

Tripling the Census of Dwarf AGN Candidates Using DESI Early Data

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ABSTRACT

Using early data from the Dark Energy Spectroscopic Instrument (DESI) survey, we search for AGN signatures in 410,757 line-emitting galaxies. By employing the BPT emission-line ratio diagnostic diagram, we identify AGN in 75,928/296,261 ($\approx 25.6\%$) high-mass ($\log(M_*/M_\odot) > 9.5$) and 2,444/114,496 ($\approx 2.1\%$) dwarf ($\log(M_*/M_\odot) \leq 9.5$) galaxies. Of these AGN candidates, 4,181 sources exhibit a broad H α component, allowing us to estimate their BH masses via virial techniques. This study more than triples the census of dwarf AGN as well as that of intermediate-mass black hole (IMBH; $M_{\text{BH}} \leq 10^6 M_\odot$) candidates, spanning a broad discovery space in stellar mass ($7 < \log(M_*/M_\odot) < 12$) and redshift ($0.001 < z < 0.45$). The observed AGN fraction in dwarf galaxies ($\approx 2.1\%$) is nearly four times higher than prior estimates, primarily due to DESI’s smaller fiber size, which enables the detection of lower luminosity dwarf AGN candidates. We also extend the $M_{\text{BH}} - M_*$ scaling relation down to $\log(M_*/M_\odot) \approx 8.5$ and $\log(M_{\text{BH}}/M_\odot) \approx 4.4$, with our results aligning well with previous low-redshift studies. The large statistical sample of dwarf AGN candidates from current and future DESI releases will be invaluable for enhancing our understanding of galaxy evolution at the low-mass end of the galaxy mass function.

1. INTRODUCTION

Supermassive Black Holes (SMBHs; $M_{\text{BH}} \gtrsim 10^6 M_\odot$) are found at the centers of all bulge-dominated galaxies with stellar masses $M_* \gtrsim 10^{10} M_\odot$ (Kormendy & Richstone 1995; Magorrian et al. 1998; Kormendy & Ho 2013), yet their origin is far from understood. Theoretical studies suggest that they grow via accretion and mergers from initial “seed” black holes (BHs) formed early in the Universe (Volonteri 2010). While these early BHs at high redshifts are difficult to detect with current capabilities, dwarf ($M_* \leq 3 \times 10^9 M_\odot$) galaxies in the nearby universe can host lower mass central BHs that can help constrain the BH seed formation models (Volonteri 2010; Greene 2012).

The search for central BHs in dwarf galaxies, especially for the still elusive Intermediate-mass Black Holes

(IMBHs; $M_{\text{BH}} \leq 10^6 M_\odot$), has been actively pursued over the past decade (see Mezcua 2017; Greene et al. 2020; Reines 2022, for reviews). The accretion of matter onto these BHs powers active galactic nuclei (AGN), releasing a large amount of energy across the electromagnetic spectrum. In the optical regime, emission lines arising from ionized gas can be used to search for signatures of AGN photoionization. For instance, the BPT (“Baldwin, Phillips & Terlevich”; Baldwin et al. 1981; Veilleux & Osterbrock 1987) emission-line diagnostic diagrams have been widely employed to identify hundreds of dwarf AGN candidates (Reines et al. 2013; Mezcua & Domínguez Sánchez 2020; Molina et al. 2021; Polimera et al. 2022; Salehirad et al. 2022; Siudek et al. 2023; Mezcua & Domínguez Sánchez 2024). Beyond optical diagnostics, other methods such as infrared color-color diagrams (Kaviraj et al. 2019; Lupi et al. 2020; Latimer et al. 2021b), radio observations (Mezcua et al. 2019; Reines et al. 2020; Davis et al. 2022), X-ray emission (Lemons et al. 2015; Pardo et al. 2016; Mezcua et al. 2016, 2018; Birchall et al. 2020; Latimer et al. 2021a;

Bykov et al. 2024; Sacchi et al. 2024), and variability techniques (Baldassare et al. 2020; Burke et al. 2022; Ward et al. 2022) have been utilized to increase the census of dwarf AGN candidates. Despite this progress, questions remain regarding the prevalence of AGN in dwarf galaxies.

Optical spectroscopy also offers an avenue to infer key physical properties of AGN, including their luminosity and BH masses. The gravitational influence of the BH accelerates the gas in its vicinity, resulting in broad emission lines in the spectrum. The broad H α emission from single-epoch spectroscopy is frequently used to estimate BH masses in galaxies through virial techniques (Greene & Ho 2005; Reines et al. 2013; Baldassare et al. 2015; Reines & Volonteri 2015; Suh et al. 2020). Baldassare et al. (2015) identified a BH with a mass of $\approx 50,000 M_{\odot}$ in a nearby dwarf galaxy, which is the lowest mass BH detected to date. However, further efforts to identify more of such lower-mass BHs are essential for discerning the BH seed formation models.

Scaling relations between the mass of the central SMBH and various galaxy properties such as the mass/luminosity of the stellar bulge (Ferrarese & Merritt 2000; Marconi & Hunt 2003; Lauer et al. 2007; Gültekin et al. 2009; McConnell & Ma 2013), the velocity dispersion of stars in the bulge (Ferrarese & Merritt 2000; Gebhardt et al. 2000; Gültekin et al. 2009; McConnell & Ma 2013), and the galaxy stellar mass (Reines & Volonteri 2015; Suh et al. 2020), have been extensively studied. The tightness of the observed correlations suggests that SMBHs and their host galaxies co-evolve (Kauffmann & Haehnelt 2000; Kormendy & Ho 2013). However, whether this co-evolution extends to lower-mass galaxies is unknown.

The low-mass end of the scaling relations can provide insight into the BH seed formation mechanisms and into the efficiency of BH growth in dwarf galaxies (Greene et al. 2020). By measuring the stellar velocity dispersion (σ_{\star}) of eight broad-line candidates from Reines et al. (2013), Baldassare et al. (2020) extended the $M_{\text{BH}} - \sigma_{\star}$ relation down to $\log(M_{\star}/M_{\odot}) \approx 8.96$. They found that the dwarf galaxies are in good agreement with the extrapolation of the existing relation (Kormendy & Ho 2013). In contrast, using a sample of 127 low-mass Seyfert 1 galaxies, Martín-Navarro & Mezcua (2018) found a flattening at the low-mass end of the $M_{\text{BH}} - \sigma_{\star}$ relation. However, measuring σ_{\star} in low-mass systems is difficult to extend to a larger sample and to farther distances due to faintness of the targets and the limitations of current telescopes and instrumentation. Therefore, even though the $M_{\text{BH}} - \sigma_{\star}$ relation usually shows the tightest correlation, the $M_{\text{BH}} - M_{\star}$ relation

is preferred for both extending the scaling relations to lower galaxy masses and/or for comparing to higher redshifts.

Using a sample of 262 broad-line AGN and 79 galaxies with dynamical BH masses, including fourteen dwarf galaxies, Reines & Volonteri (2015) measured the $M_{\text{BH}} - M_{\star}$ relation down to $\log(M_{\star}/M_{\odot}) \approx 9.0$. They found two distinct scaling relations for early-type and late-type galaxies, with the former having a higher normalization than the latter and the dwarf galaxies falling on the tail of the late-type galaxy relation. More recently, Mezcua et al. (2023) and Mezcua et al. (2024) found nineteen low-mass galaxies at $z \approx 0.9 - 3$ with over-massive BHs that reside $\gtrsim 2$ dex above the $M_{\text{BH}} - M_{\star}$ relation. Several such over-massive BHs were also discovered at higher redshifts, $z \approx 4 - 11$ using observations from the James Webb Space Telescope (JWST; Harikane et al. 2023; Maiolino et al. 2023; Übler et al. 2023). However, these high-redshift studies are subject to observational bias, as they predominantly detect luminous AGN. Overall, these studies are constrained by limited sample sizes at the low-mass end, and the scaling relation remains poorly constrained at both low stellar and BH masses, even at low redshifts.

In this paper, we use early spectroscopic data from the Dark Energy Spectroscopic Instrument (DESI; DESI Collaboration et al. 2016a,b, 2022) survey to identify AGN in galaxies spanning a wide range of stellar masses ($6 \leq \log(M_{\star}/M_{\odot}) < 12$), specifically to increase the census of AGN in dwarf galaxies, and to extend the $M_{\text{BH}} - M_{\star}$ scaling relation down to lower galaxy masses. The early DESI data is the largest sample of optical spectra to date, encompassing nearly 1.5 million unique galaxies at $z \leq 0.45$ for our analysis.

This paper is organized as follows. Section 2 describes the spectroscopic and photometric data used in the paper. We present the estimation of stellar masses and emission-line measurements of the targets in Section 3. Sections 4 and 5 details the AGN identification and the overall $M_{\text{BH}} - M_{\star}$ scaling relation, respectively. We discuss our results in Section 6 and summarize our conclusions in Section 7. Throughout the paper, we assume the Chabrier initial mass function (IMF; Chabrier 2003), and the Planck Collaboration et al. (2020) cosmology with $H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega = 0.315$. All wavelengths are presented in vacuum wavelengths, and all magnitudes are given in the AB system (Oke & Gunn 1983).

2. DATA

2.1. Spectroscopy

DESI is a 5000-fiber multi-object spectrograph on the 4-meter Mayall telescope at Kitt Peak National Observatory (KPNO), covering a spectral range of 3600 Å to 9800 Å. The resolving power of the instrument ranges from 2000 at 3600 Å to 5500 at 9800 Å (DESI Collaboration et al. 2022; Silber et al. 2023; Miller et al. 2024). This instrument will be used to conduct a cosmological survey over an area of $\approx 14,000 \text{ deg}^2$ over five years and will obtain optical spectra of nearly 35 million galaxies and quasars (Levi et al. 2013; DESI Collaboration et al. 2016a,b; Schlafly et al. 2023). DESI completed its survey validation (SV) observations in May 2021, and is currently carrying out its main survey. The SV data, covering $\approx 1,400 \text{ deg}^2$ of the sky, is released as the DESI Early Data Release (EDR; DESI Collaboration et al. 2023, 2024). We use the entire DESI EDR and 20% of Year 1 (DA0.2) data for analysis in this paper.

DESI targets are divided into five primary classes: 1) Milky Way Survey (MWS; Cooper et al. 2023), 2) Bright Galaxy Survey (BGS; Ruiz-Macias et al. 2020; Hahn et al. 2023; Juneau et al. 2024), 3) Luminous Red Galaxies (LRG; Zhou et al. 2020, 2023), 4) Emission Line Galaxies (ELG; Raichoor et al. 2020, 2023), and 5) Quasars (QSO; Yèche et al. 2020; Chaussidon et al. 2023). These are further complemented by secondary targets via spare fibers (SCND; see Appendix of DESI Collaboration et al. 2023; Darragh-Ford et al. 2023; Fawcett et al. 2023). This target selection is validated based on a thorough visual inspection of the SV spectra (Alexander et al. 2023; Lan et al. 2023). Some sources can be targeted in multiple targeting classes based on their selection criteria. The DESI targeting selection is described in detail by Myers et al. (2023).

The spectra obtained from DESI are reduced using the DESI spectroscopic pipeline (Guy et al. 2023), and the redshifts are obtained by the Redrock redshift-fitting pipeline (Brodzeller et al. 2023; Anand et al. 2024, Bailey et al., in preparation). The DESI EDR and DA0.2 spectra are reduced and released as ‘*fuji*’ and ‘*guadalupe*’ internal data releases, respectively. Combining the redshift catalogs from both these releases results in 6,059,937 spectra of 5,859,563 unique targets. For objects with multiple spectra, we choose the “best spectrum” based on the ZCAT_PRIMARY flag. This prioritizes the spectrum that has no issues with fiber and redshift measurements. If multiple spectra pass these criteria, then we choose the highest signal-to-noise ratio spectrum as the “best spectrum” for the object (see Section 3.3.3 in DESI Collaboration et al. (2023) for more information). After selecting the unique spectra of all objects, we apply the following data quality cuts:

COADD_FIBERSTATUS = 0, ZWARN = 0 or 4. This selects 4,323,517 sources that have been observed without any fiber issues and have good redshift measurements. Of these, we select sources that are assigned spectroscopic types of GALAXY or QSO by Redrock, resulting in a total of 3,483,455 sources. Of these, 1,628,394 sources have redshifts in the range of $0.001 \leq z \leq 0.45$. The lower redshift limit is to exclude contamination from Galactic sources. Given that we focus on identifying AGN candidates using standard emission-line ratio diagnostics (Section 4.1), the upper redshift limit is determined by the availability of [SiII] $\lambda\lambda 6717, 6731$ emission lines in the DESI spectra (see Section 3.2 for more information).

For some QSO targets, the redshifts determined by Redrock were found to be incorrect, resulting in the presence of high-redshift contaminants in our sample (Alexander et al. 2023). To accurately determine their redshifts, the DESI team used a machine learning algorithm called QuasarNet, which is a deep convolutional neural network classifier specifically designed to identify quasars and their redshifts. Of the 1,628,394 Redrock redshifts, we find that 4,286 are classified as high-redshift ($z \gtrsim 0.5 - 4$) quasars by QuasarNet. We remove these from our selection, resulting in a spectroscopic sample of 1,624,108 sources in our redshift range of interest.

2.2. Photometry

The primary DESI targets are selected based on the DESI Legacy imaging surveys (Dey et al. 2019). The ninth data release for this survey (DR9) comprises a set of optical and infrared imaging data covering the entire $14,000 \text{ deg}^2$ of the DESI survey (Schlegel et al., in preparation). The photometric catalog consists of optical imaging data from three different surveys: The Beijing-Arizona Sky Survey (BASS; Zou et al. 2017), the DECam Legacy Survey (DECaLS), and the Mayall z -band Legacy Survey (MzLS). Furthermore, it also includes the WISE/NEOWISE (unWISE; Lang 2014; Meisner et al. 2016, 2017) coadd images from the Wide-field Infrared Space Explorer (WISE; Wright et al. 2010).

Imaging from the Legacy Surveys is processed using inference modeling with the *Tractor* code (Lang et al. 2016). This produces a catalog that contains photometry in g , r , and z bands, based on an optimal model

<https://desidatamodel.readthedocs.io/en/latest/bitmasks.html#fiberstatus-bit-definitions>
<https://desidatamodel.readthedocs.io/en/latest/bitmasks.html#zwarn-bit-definitions>
<https://github.com/dstndstn/tractor>

of the source morphology. It also includes mid-IR photometry measured from the forced photometry of the unWISE coadds using the optically derived model. This detects fainter sources than the traditional approach of WISE photometry (Lang et al. 2016). Furthermore, the morphology (TYPE) and Sérsic index (SERSIC) of each source are also computed based on this model.

The optical photometry is corrected for Galactic extinction using the dust emission maps from Schlegel et al. (1998). The extinction values for the WISE filters are derived from Fitzpatrick (1999), using the recommendations by Schlafly & Finkbeiner (2011). These are reported in the LS DR9 catalog in linear units of Milky Way transmission.

In addition to the primary DESI targets, the spectral data from the survey also includes secondary targets as well as targets of opportunity, which might not always have the Legacy Survey photometry. Given that our analysis requires the stellar mass calculation using this photometry, we select the 1,623,425 objects that have DR9 photometry. Additionally, we apply two quality cuts that remove false detections, extremely faint sources, and a significant fraction of fragmented sources:

$$\text{SNR} \geq 5 \text{ in } g, r, z \text{ bands}$$

$$\text{FRACFLUX} \leq 0.25 \text{ in } g, r, z \text{ bands}$$

We do not apply any cuts on the WISE photometry to include faint dwarf galaxies, which might not always have good available WISE detections. Given the strong cuts on optical photometry, we will instead focus on quality cuts based on stellar mass estimates (Section 3.1). The above cuts result in 1,492,821 unique sources with good spectra and valid photometry as the starting sample for our analysis.

3. METHODS

3.1. *Stellar Masses*

We fit the spectral energy distributions (SED) using Code Investigating GALaxy Emission (CIGALE v.22.1; Boquien et al. 2019) to estimate the stellar masses of our sample while accounting for the AGN contribution. We use Bruzual & Charlot (2003) single stellar population models assuming a Chabrier IMF (Chabrier 2003) and solar metallicity. Furthermore, we consider a delayed star formation history (SFH) model with an optional exponential burst to generate the grid of models. We include the standard nebular emission model from Inoue (2011) and the dust attenuation model using the Calzetti et al. (2000) attenuation curve. The reprocessed dust emission is modeled adopting the dust emission models of Dale et al. (2014), whereas the AGN

emission is modeled using the models from Fritz et al. (2006). CIGALE simultaneously fits the AGN and galaxy component using all available photometry (g , r , z , W1, W2, W3, and W4) at the spectroscopic redshift of each galaxy. It returns the estimates for the main galaxy properties, including stellar mass, star formation rate, and the relative contribution of the dusty AGN torus to the total infrared luminosity. In cases where the fit is consistent with no or negligible AGN contribution, CIGALE outputs the AGN fraction to be zero. The quality of fit is expressed by reduced χ^2 , and the estimates and errors of physical properties are the likelihood-weighted mean and standard deviations of the probability distribution function, respectively (Boquien et al. 2019). The physical properties of galaxies and AGN for both *fuji* and *guadalupe* releases are generated as value-added catalogs (VACs), and the former is now publicly available with DESI EDR (Siudek et al. 2024).

CIGALE works better when the mid-IR photometry is available, but it will still converge to a solution with the confident optical photometry (in grz bands) and any available WISE photometry (Siudek et al. 2024). We therefore do not place any constraints on the WISE photometry of sources (Section 2.2), and instead focus on the following quality cuts to select sources with confident stellar masses:

$$\chi^2_{\text{CIGALE}} \leq 10$$

$$\log(M_*/M_\odot) \geq 6$$

$$\text{Error in } \log(M_*/M_\odot) \leq 0.5 \text{ dex}$$

CIGALE computes two estimates of the different parameters based on the best-fit model (**best**) and the likelihood-weighted mean measured from the probability density function marginalized over all the parameters (**bayes**). The comparison between the two measurements is parametrized by FLAG.MASSPDF, which is defined as $\log(M_{\text{best}}/M_{\text{bayes}})$. To select accurate stellar mass measurements, we further apply the following cut as recommended by the CIGALE VAC (see Mountrichas et al. 2021; Siudek et al. 2024).

$$0.2 \leq \text{FLAG.MASSPDF} \leq 5$$

This results in 1,358,177 sources with stellar masses ranging from $\log(M_*/M_\odot) = 6.0 - 12.3$, with a median of $\log(M_*/M_\odot) = 10.3$. The left panel of Figure 1 shows the 2D distribution of these sources in the $\log(M_*/M_\odot) - z$ space. The source density peaks at

<https://data.desi.lbl.gov/doc/releases/edr/vac/cigale>

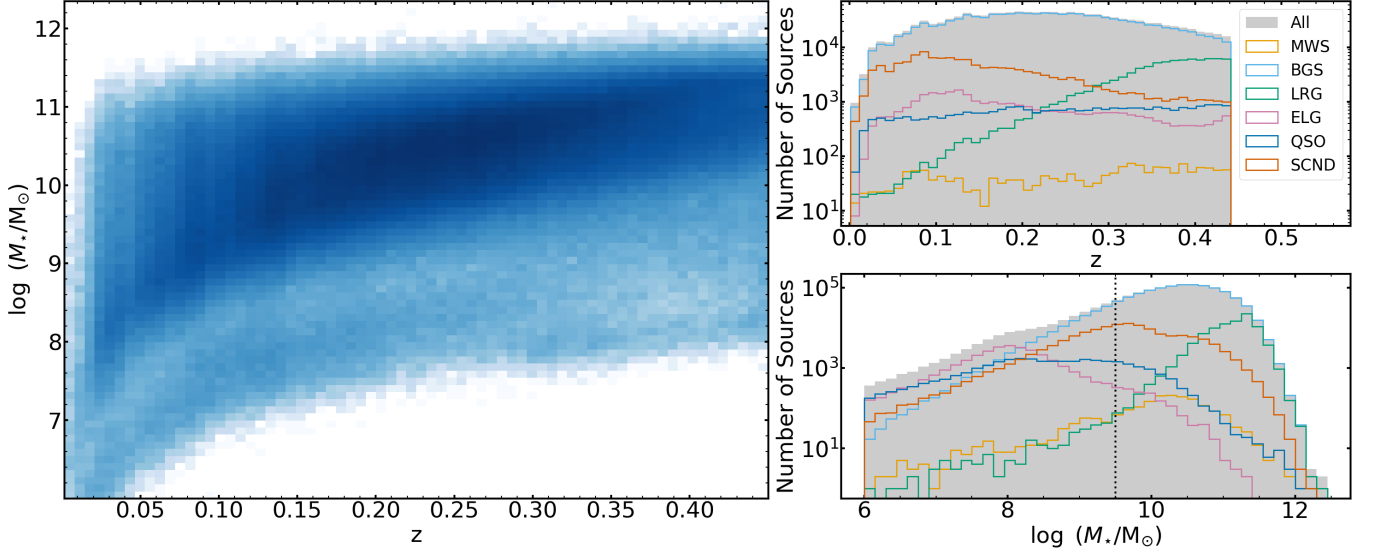


Figure 1. *Left:* 2D density distribution of 1,358,177 sources in the $\log(M_*/M_\odot) - z$ space. *Top Right:* Redshift distribution of the sources divided by their DESI targeting type. The underlying gray histogram is the redshift distribution of all the sources. *Bottom Right:* Stellar mass distribution of the sources divided by their DESI targeting type. The underlying gray histogram is the stellar mass distribution of all the sources. The vertical dotted line denotes the separation of dwarf ($\log(M_*/M_\odot) \leq 9.5$) galaxies and high-mass ($\log(M_*/M_\odot) > 9.5$) galaxies. Some objects are targeted in more than one target class, therefore, some of the sources are duplicated in different histograms.

$\log(M_*/M_\odot) \approx 10.5$ and $z \approx 0.2$. We find that the stellar masses at $z \approx 0.45$ extend down to $\log(M_*/M_\odot) \approx 7.5$. There are two overlapping distributions varying with redshift, with the higher-density sample extending from low-redshift dwarf galaxies to high-redshift massive galaxies. The lower-density sample hosts the majority of dwarf galaxies in our sample. This is primarily due to the DESI targeting selection (see Section 2.1) as shown on the right panel of the Figure. The top-right panel shows the redshift distribution of sources, divided by their DESI target type. All the target types are uniformly distributed across our redshift range of interest, except the LRG targets that have a redshift distribution skewed toward the high end of the redshift range. The MWS sources are intended to be Milky Way stars by the targeting criteria, but **Redrock** recovers them as **GALAXY** or **QSO**. We also see that BGS targets dominate across all redshifts. This is expected because BGS is designed to focus on low redshifts, while LRG, ELG, and QSO targets focus on $z > 0.5$. The bottom-right panel shows the stellar mass distribution of the sources, distributed between different target types. The dotted vertical line denotes the separation of dwarf galaxies from high-mass galaxies that we consider in this paper. Of the 1,385,177 total sources, we have 222,680 dwarf galaxies (with $\log(M_*/M_\odot) \leq 9.5$) and 1,135,497 high-mass galaxies (with $\log(M_*/M_\odot) > 9.5$). The BGS targets constitute the majority of both dwarf galaxies and high-mass galaxies in our sample. The rest of the

dwarf galaxies come from SCND, ELG, and QSO, with $<1\%$ sources from LRG and MWS. On the other hand, the remaining high-mass galaxies are primarily LRG and SCND targets and $<1\%$ are from ELG, QSO, and MWS. We discuss the impact of these targeting selections on AGN identification in Section 4.3.

3.2. Emission-Line Measurements

To accurately determine the emission-line ratios for AGN selection and to estimate the BH masses using virial techniques, we need careful measurements of the flux and width (σ) values of various emission lines. For this purpose, we developed a Python-based emission-line fitting code (**EmFit**), which uses a non-linear least squares fitting algorithm, for fitting $H\beta$ $\lambda 4861$, $[OIII]\lambda 5007$, $[NII]\lambda\lambda 6548, 6584$, $H\alpha$ $\lambda 6563$, and $[SII]\lambda\lambda 6717, 6731$ emission lines. The code includes testing for extra components for $[OIII]$, $[SII]$, and $H\alpha$. We run **EmFit** on all 1,624,108 sources with good spectra, irrespective of photometry and stellar mass measurements. We describe the fitting procedure in this subsection.

For each object, we correct the DESI spectrum for galactic reddening using the **Fitzpatrick (1999)** dust extinction law. We then obtain the stellar continuum from **FastSpecFit** (**Moustakas et al. 2023**, J. Moustakas et

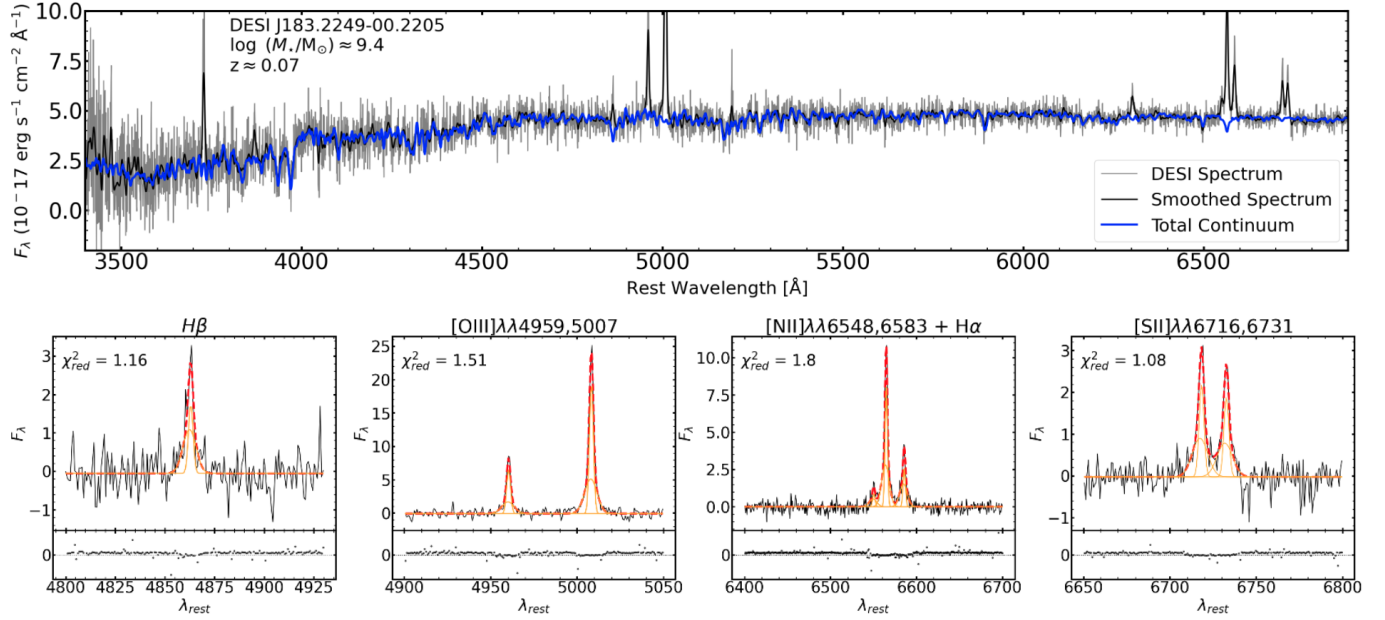


Figure 2. Example fit of a dwarf galaxy spectrum via the default mode. *Top:* The rest-frame spectrum, the smoothed spectrum, and the total continuum fit are plotted in gray, black, and blue, respectively. The stellar mass and redshift of the source are mentioned in the panel. *Bottom:* Best-fit models to the continuum-subtracted emission line spectrum in the regions of interest - $H\beta$, $[OIII]$, $[NII] + H\alpha$, and $[SII]$ - from left to right. The spectrum is shown in black, while the best-fit models are shown in dashed red. The individual narrow and outflow components are plotted in orange. The reduced χ^2 values for each of the fits are given in the upper left corner of the panels. The fractional residuals are plotted as gray points in the bottom panels for each of the fits.

al., in preparation). We use *FastSpecFit* v3.2 for *fuji* and v3.1 for *guadalupe*; the VAC for DESI-EDR is publicly available. Using 168 composite stellar population templates of varying age, stellar metallicity, and dust attenuation, *FastSpecFit* models the stellar continuum. The spectra are then corrected for any residual, unmodeled flux by constructing a “smooth” continuum using a sliding median with iterative outlier-clipping. We subtract this total continuum from the observed spectrum and convert the resulting emission-line spectrum to rest-frame.

We have two different fitting modes for the rest-frame spectra: the “default” mode and the “Extreme Broad Line (EBL)” mode. The EBL sources are defined here as sources where the broad component of $H\alpha$ extends up to the $[SII]$ region. We compare the blue side of $[SII]$ emission-lines ($6600 - 6670 \text{ \AA}$) to the red side ($6700 - 6900 \text{ \AA}$) and if the difference between the median flux density between the two sides is $> 0.5 \times 10^{-17} \text{ ergs s}^{-1} \text{ cm}^{-2}$ and if this flux density from the blue side is at least five times higher than the red side, we flag it as an EBL source. Of the 1,624,108 sources, 3,457 sources (0.21%) are fit via the EBL mode, while the rest are fit via the default mode.

For both modes, we model each emission line using one or more Gaussian functions, which are constrained to have positive flux. We also include a zero-order polynomial to each fit, as a proxy for any residual continuum around the emission lines. Adding an extra Gaussian component to a fit typically improves the fit and decreases its reduced χ^2 . To evaluate the statistical significance of this improvement, we compute the χ^2 difference, $\Delta\chi^2$, with and without the extra component. By Wilk’s theorem, the $\Delta\chi^2$ asymptotically approaches a χ^2 distribution under the null hypothesis of a simple fit with a single Gaussian (Wilks 1938). Thus, we convert the $\Delta\chi^2$ into a tail probability (p -value), and we reject the null hypothesis when p -value is less than 3×10^{-7} . This provides at least a 5σ confidence for the existence of an extra component.

We first describe our default fitting method, followed by the EBL fitting method for the flagged sources.

3.2.1. Default Fitting Mode

For the sources that are not flagged as EBL sources, we divide the rest-frame emission-line spectrum into four windows: 1) $4700 \text{ \AA} \leq \lambda_{rest} \leq 4930 \text{ \AA}$ for the $H\beta$ region; 2) $4900 \text{ \AA} \leq \lambda_{rest} \leq 5100 \text{ \AA}$ for the $[OIII]$ region; 3) $6300 \text{ \AA} \leq \lambda_{rest} \leq 6700 \text{ \AA}$ for the $[NII] + H\alpha$ region; and 4) $6630 \text{ \AA} \leq \lambda_{rest} \leq 6900 \text{ \AA}$ for the $[SII]$ region.

We first fit the [SII] doublet with a pair of Gaussian profiles tied to have the same redshift and same intrinsic linewidth in velocity space. In addition to the one-component fit, we also test for a two-component fit to the [SII] doublet, such that the amplitude ratio of the two components is equal for the lines (following Reines et al. 2013). When the spectrum is noisy, there is a risk that the model includes a low-amplitude broad component to fit the continuum. To avoid this unphysical scenario, the width of the second component is allowed to vary up to 600 km s^{-1} . However, if in such a scenario, a single component has a width $> 450 \text{ km s}^{-1}$, we switch back to a two-component model. We apply quality cuts based on this scenario to remove unphysical fits (see Section 3.2.4). The two-component model is accepted if the p -value from the $\Delta\chi^2$ provides a $> 5\sigma$ confidence. In such a case, we label the narrower component as the primary component and the broader component as the secondary component. The second component can either be an “outflow” component or a second narrow peak in double-peaked emission line sources (see Appendix A). Only 11,000 ($\approx 0.8\%$) sources require a second component. The [SII] emission line profile has been shown to generally match other narrow emission lines (Greene & Ho 2004; Reines et al. 2013). We, therefore, use the final [SII] model as a template for the [NII] and H α emission lines.

We then fit the [NII] + H α complex, where the redshifts of the [NII] and H α lines are tied to the [SII] lines. The amplitude ratio of [NII] $\lambda 6583$ /[NII] $\lambda 6548$ is fixed to the theoretical value of 2.96 (Acker et al. 1989). When [SII] is best-fit with a single component model, the width of [NII] lines is fixed to the width of [SII] lines in velocity space, and the width of the narrow H α component is initially allowed to increase up to 30% of the [SII] width (similar to Reines et al. 2013). If H α does not satisfy this constraint, the width of the narrow H α is also held fixed to that of the [SII] component. For the two-component [SII] model, all the three emission lines - [NII] doublet and H α - are also considered to have two components such that the width of the respective components is fixed to the [SII] components in velocity space. Additionally, the separation between the two components is also fixed as measured from the [SII] template. Having the same second component as [SII] lines is important to achieve a physically probable broad component after removing the contribution from the second component (see Figure 2 and Appendix B). For both one and two-component fits, we further test for a broad component (H α ;b) with a minimum FWHM (H α ;b) $> 300 \text{ km s}^{-1}$, based on the p -value from the $\Delta\chi^2$ with and without a broad component. The broad component is accepted when it delivers

$> 5\sigma$ confidence. However, this component is rejected if this component is narrower than the second component.

We use the resulting H α fit as a template for the H β fit and the number of components of H β is fixed to be the same as H α . The redshifts and widths of all the available H β components (primary, second, and broad) are fixed to the widths of the respective H α components in velocity space. Only the amplitude of the components is allowed to vary.

Given that the [OIII] profile can exhibit a blue-shifted outflow component and does not match the profile of other narrow emission lines, we fit the [OIII] doublet separately. We fix the relative redshifts of the peaks, fix the amplitude ratio of [OIII] $\lambda 5007$ /[OIII] $\lambda 4959$ to 2.98 (Dimitrijević et al. 2007), and add the condition that the widths of the two lines are equal in velocity space. Both one and two-component models are tested and the two-component fit is accepted if the p -value from the $\Delta\chi^2$ satisfies the 5σ confidence cut. Similar to the [SII] model, the narrower component is taken as the primary component, and the broader component can either be an outflow component or a second component (see Appendix A).

Figure 2 shows an example of a dwarf galaxy ($\log(M_\star/M_\odot) \approx 9.4$) spectrum fit via the default mode. The top panel shows the best-fit of the stellar continuum (in blue) from FastSpecFit overplotted on the DESI spectrum (in gray). The resulting emission line spectrum (in black) and the best-fit models (in red) are shown in the bottom panel. We see that all the emission lines contain a second component (a possible outflow in this case). The primary and outflow Gaussian components are shown in orange, and the reduced χ^2 values are shown in each of the panels. This galaxy is a dwarf AGN candidate (see Section 4) and shows the importance of adding a second component in the narrow emission lines.

3.2.2. Extreme Broad Line Fitting Mode

For the sources that are flagged as EBL sources, we divide the rest-frame emission-line spectrum into two windows: 1) $4700 \text{ \AA} \leq \lambda_{rest} \leq 5100 \text{ \AA}$ for the H β + [OIII] region; and 2) $6300 \text{ \AA} \leq \lambda_{rest} \leq 6900 \text{ \AA}$ for the [NII] + H α + [SII] region.

We first fit the [NII] + H α + [SII] emission-lines with a single Gaussian component for each of the narrow lines and an extra broad Gaussian component. In the case of EBL sources, multiple broad components might be needed for properly fitting the complex emission line profile (Greene & Ho 2005; Liu et al. 2019). However, we approximate the complex spectrum with a single broad Gaussian component for this work. The amplitude ratio of [NII] $\lambda 6583$ /[NII] $\lambda 6548$ is again fixed to the theoretical

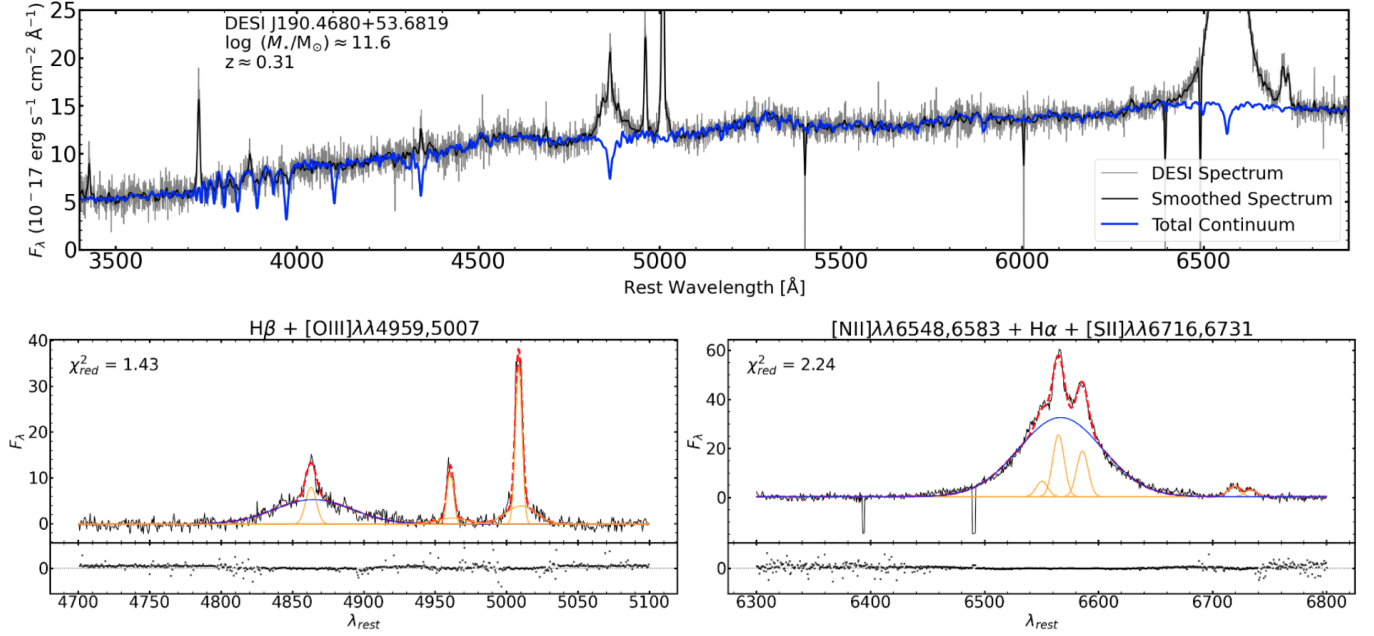


Figure 3. Example fit of a high-mass galaxy spectrum via the EBL mode. *Top:* The rest-frame spectrum, the smoothed spectrum, and the total continuum fit are plotted in gray, black, and blue, respectively. The stellar mass and redshift of the source are mentioned in the panel. *Bottom:* Best-fit models to the continuum-subtracted emission line spectrum in the regions of interest - $H\beta + [OIII]$ (left) and $[NII] + H\alpha + [SII]$ (right). The spectrum is shown in black, while the best-fit models are shown in dashed red. The individual narrow and outflow components are plotted in orange, while the broad Balmer components are plotted in blue. The reduced χ^2 values for each of the fits are given in the upper left corner of the panels. The fractional residuals are plotted as gray points in the bottom panels for each of the fits.

value of 2.96 (Acker et al. 1989). The redshifts of all the narrow components ($[NII]$ doublet, $H\alpha$, and $[SII]$ doublet) are tied together and their widths are constrained to be equal in velocity space. In some sources, a noisy spectrum is selected as an EBL source. Their fits using this mode lead to an unrealistic broad $H\alpha$ component. Using visual inspection, we find that such sources are poorly fit with broad $H\alpha$ widths $< 1000 \text{ km s}^{-1}$. We therefore use this criterion ($\sigma(H\alpha; b) < 1000 \text{ km s}^{-1}$) to pick such sources and rerun their fitting using the default mode. The median FWHM of broad $H\alpha$ components for the sources that are fit with the EBL mode is $\approx 2000 \text{ km s}^{-1}$.

For the $H\beta + [OIII]$ region, we use the $H\alpha$ model as a template for the $H\beta$ model and the $[OIII]$ lines are fit independently. We fix the redshifts and widths of the $H\beta$ components to scale with the $H\alpha$ components. The redshifts, amplitudes, and widths of the $[OIII]$ components are tied as mentioned in the default mode. Both one- and two-component models are tested for the $[OIII]$ lines, and the two-component fit is allowed if the p -value from the $\Delta\chi^2$ is less than the 5σ -confidence cut.

Figure 3 shows an example of the best-fit of a high-mass EBL source ($\log(M_*/M_\odot) \approx 11.6$). The panel shows the total continuum from **FastSpecFit** in blue, overplotted on the spectrum. The bottom panels show

the best-fits in the $H\beta + [OIII]$ and $[NII] + H\alpha + [SII]$ regions. The narrow and outflow components are shown in orange, while the broad Balmer components are shown in blue. The $[OIII]$ lines in this galaxy clearly show evidence of outflows.

3.2.3. Measurements and Uncertainties

We compile the amplitude, mean, and standard deviation of all the detected Gaussian components from the best-fit model. The fluxes and widths (σ) are computed using these parameters and the resulting width is corrected for instrumental resolution by subtracting the resolution element in quadrature. To estimate the fit uncertainties, we consider a Gaussian error distribution with standard deviation derived from the inverse variance at each pixel of the spectrum. We vary the spectrum within this distribution and repeat the fitting procedure a hundred times. The uncertainties are estimated as the standard deviation of all measurements from these iterations. We assume that the pixels are uncorrelated and the errors are therefore underestimated. In addition to the flux and σ measurements, we also measure the noise around the emission lines as the root-mean-square (rms) of the continuum around the lines. We also make note of **PROB_BROAD** as the fraction of iterations in which the broad $H\alpha$ component is measured

with non-zero flux. This is especially important for selecting broad-line candidates when the spectra are noisy.

The emission line ratio measurements require total fluxes from the narrow component of the emission lines (Section 4). As mentioned earlier, some of the second components in [SII],[OIII],[NII], and H α appear as narrow components for double-peaked emission line sources. We add the fluxes from the two components for such sources. The method of picking these double-peaked sources is described in Appendix A.

3.2.4. Applying Quality Cuts

Even after the detailed careful fitting process, the fits to some noisy spectra lead to poor representations of the observations and unphysical flux and sigma values. One such instance is when the stellar continuum subtraction is erroneous and creates a non-physical jump between the continuum on either side of the emission lines. This is especially prominent in fitting [SII] lines, leading to broad second components. We remove these sources by applying the following cut:

$$\sigma_{[\text{SII}],2} < 700 \text{ km s}^{-1}$$

where $\sigma_{[\text{SII}],2}$ is the width of the second [SII] component. Another issue is related to the forced fitting of a negative continuum and an extremely high-velocity width narrow component to account for the noisy spectrum. These affect all the fitting windows and we remove them by applying an upper limit on the width of the primary components:

$$\sigma < 1000 \text{ km s}^{-1} \text{ for [SII], [NII], [OIII], H}\alpha, \text{ or H}\beta$$

These quality cuts result in 1,350,112 sources across the stellar mass and redshift range, which we use for our analysis.

3.3. Selecting Line-Emitting Galaxies

We explore two complementary ways of detecting AGN candidates in this paper: emission-line ratios and broad H α detection (Section 4). This depends on the accurate detection of four emission lines: H β , [OIII] λ 5007, H α , and [NII] λ 6583. We apply the following SNR and AoN (amplitude-over-noise) cuts on these four lines for selecting the sample of line-emitting galaxies:

$$\begin{aligned} &\text{SNR} \geq 3 \text{ for [OIII], H}\alpha, \text{ [NII]} \\ &(\text{SNR} \geq 1) \text{ \& } (\text{AoN} \geq 1) \text{ for H}\beta \end{aligned}$$

It is often found that H β lacks significant detection in galaxies and setting a higher threshold often removes good candidates that would have been classified as AGN (Cid Fernandes et al. 2010). We therefore use a lower

threshold for H β compared to the other emission lines. For double-peaked sources, we consider the fluxes as the sum of the fluxes of the two components, and their errors are added in quadrature for computing the SNR values. We still consider the AoN of the primary H β component for these sources as a way of ensuring that the components are detected over the noise of the spectrum. We have 459,208 sources that satisfy the SNR criteria for [OIII], H α , and [NII], of which 48,451 sources are rejected based on the H β cuts. This results in 410,757 line-emitting galaxies, of which 114,496 are dwarf galaxies (51.6%), and the rest of 296,261 (26.3%) are high-mass galaxies. We observe broad H α (H α ;b) detection in 13,526 of these sources. To select confident H α ;b candidates, we apply the following cuts:

$$\begin{aligned} &\text{SNR (H}\alpha\text{;b)} \geq 3 \\ &\text{SNR } (\sigma_{\text{H}\alpha\text{;b}}) \geq 3 \\ &\text{AoN (H}\alpha\text{;b)} \geq 2 \end{aligned}$$

Finally, we apply a cut on PROB_BROAD for selecting statistically likely broad component detections:

$$\text{PROB_BROAD} \geq 80\%$$

These cuts result in 6,185 broad-line (BL) candidates, and the remaining 404,572 line-emitting galaxies are considered narrow-line (NL) sources.

4. INCIDENCE OF AGN IN LINE-EMITTING GALAXIES

In this section, we search for AGN signatures in our sample of line-emitting high-mass and dwarf galaxies (Section 4.1). We further compare our identified dwarf AGN candidates with results from prior single-fiber spectroscopic surveys (Section 4.2). Lastly, we explore the variation of the observed AGN fraction with stellar mass and redshift (Section 4.3).

4.1. AGN Candidates from the [NII]-BPT Diagram

Two primary processes contribute to the photoionization of the interstellar medium (ISM) in galaxies: star formation and AGN activity. AGN produce a harder spectrum (i.e., a larger fraction of high-energy photons) than hot stars, causing identifiable signatures in the resulting emission line spectrum. Two-dimensional emission-line diagnostic diagrams, commonly known as the BPT diagrams (Baldwin et al. 1981; Veilleux & Osterbrock 1987), can be used to distinguish the primary source of ionization in galaxies and identify AGN. In this paper, we focus on the most widely used BPT diagram with [NII]/H α vs. [OIII]/H β (hereafter [NII]-BPT Diagram). We explain our choice to use only this specific diagnostic in Section 6.1.

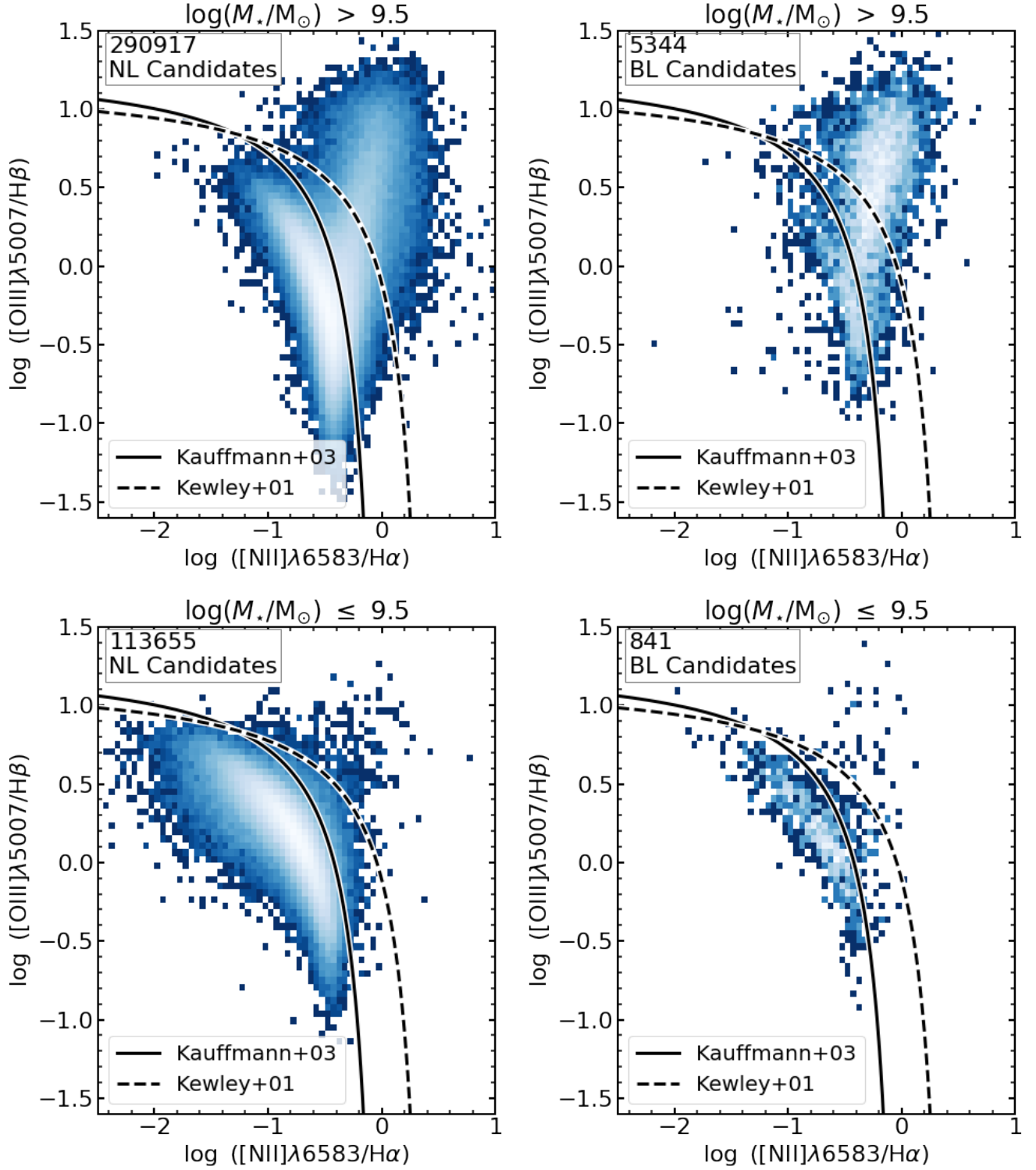


Figure 4. BPT [OIII]/H β vs [NII]/H α narrow-line diagnostic diagram for high-mass ($\log(M_*/M_\odot) > 9.5$; *Top*) and dwarf ($\log(M_*/M_\odot) \leq 9.5$; *Bottom*) galaxies, divided as NL (*Left*) and BL (*Right*) candidates. The solid line in all the panels is from Kauffmann et al. (2003), which separates the pure star-forming sources and those with AGN contribution. The dashed line represents the “maximum starburst line” using stellar photoionization models (Kewley et al. 2001).

Using pure stellar photoionization models, [Kewley et al. \(2001\)](#) suggested a “maximum starburst line” (dashed line in all panels of Figure 4), above which a non-stellar ionization source, likely an AGN, is necessary to account for the emission-line ratios. The solid line in all the panels of Figure 4 separates the sources with AGN contribution from the empirical branch attributed to star-forming galaxies ([Kauffmann et al. 2003](#)). Galaxies located between these two lines contain contributions from both AGN and star formation and are typically referred to as “composite” galaxies. For this study, we classify all sources in the AGN-dominated and composite regions as AGN candidates.

The [NII]-BPT diagnostic is metallicity-sensitive, with lower metallicity systems occupying regions with higher [OIII]/H β and lower [NII]/H α ratios ([Storchi-Bergmann et al. 1998](#); [Carvalho et al. 2020](#)). Consequently, low metallicity AGN can occupy the same regions as low metallicity starbursts ([Groves et al. 2006](#)).

4.1.1. Initial BPT Selection

We categorize the line-emitting galaxies in our sample into two groups: those exhibiting only narrow components (NL candidates) and those with a secure broad H α detection (BL candidates). While our primary goal is to identify AGN candidates, we also aim to separate the BL candidates where the presence of a broad H α component is indicative of the broad-line region (BLR) associated with an AGN. This will facilitate the estimation of their BH masses (Section 5.1) and the study of the $M_{\text{BH}} - M_{\star}$ scaling relation (Section 5.3). Thus, we focus on identifying AGN and composite sources in both NL and BL candidates (Section 3.3), even though the BPT classification is primarily through narrow components.

Figure 4 shows the [NII]-BPT diagram of high-mass galaxies (*Top Panel*) and dwarf galaxies (*Bottom Panel*) in our sample. The left panels show the BPT diagram for the NL candidates, while the right panels show the BPT diagram for the BL candidates constructed using the line ratios of the narrow components of the emission lines.

The shape of the bivariate distributions on the BPT diagram is different for dwarf and high-mass galaxies. The high-mass galaxies are characterized by a thin star-forming branch and a well-extended AGN branch for both NL and BL candidates. On the other hand, low-mass galaxies have a dense star-forming branch that extends to lower [NII]/H α ratios (< -1.4) than their counterparts. The dwarf galaxy diagrams also have sparsely populated AGN branches for both NL and BL candidates. This is not surprising as dwarf galaxies are typ-

ically star-forming galaxies and their star-forming signatures can therefore dominate the emission-line signatures. In addition, the low metallicity of dwarf galaxies leads to low [NII] and high [OIII] values ([Madden & Cormier 2019](#); [Henkel et al. 2022](#)), which explains the concentration of dwarf galaxies at the top-left corner of the star-forming branch ([Storchi-Bergmann et al. 1998](#); [Carvalho et al. 2020](#)).

Of the 296,261 high-mass line-emitting galaxies (both NL and BL candidates) in our sample, we find that 24,227 (8.2%) sources are AGN-dominated, 51,701 (17.4%) are composites, and 220,333 (74.4%) are star-forming galaxies. In contrast, we find 405/114,496 (0.3%), 2,039/114,496 (1.8%), and 112,052 (97.9%) of the dwarf line-emitting galaxies (both NL and BL candidates) reside on the AGN-dominated, composite, and star-forming branch, respectively. Table 1 describes the number of NL and BL candidates in each of the BPT regions from Figure 4.

4.1.2. Visual Inspection of BL Candidates

Of the total 6,185 BL candidates in our sample (both high-mass and dwarf galaxies), 1,748 (28.2%) lie on the star-forming branch, 1,477 (23.9%) are composites, and 2,960 (47.9%) are AGN-dominated galaxies (see Table 1). The broad H α emission in the BL candidates can originate from several processes within the galaxy. For instance, infalling virialized gas in the broad-line region (BLR) of the AGN can produce this emission. Additionally, dynamics in the accretion disk surrounding the BH, outflows driven by AGN activity, and/or star formation can contribute extra components to the H α emission line. Stellar processes, such as Type II supernovae and Luminous Blue Variables (LBVs), may also generate broad H α emission ([Smith et al. 2011](#); [Gutiérrez et al. 2017](#); [Pessi et al. 2023](#)). To distinguish between the star-formation-driven and AGN-driven broad H α sources, we focus exclusively on the BL candidates identified as AGN and composites in the [NII]-BPT diagram.

Since we push to lower widths of the broad H α component than any prior studies ([Reines et al. 2013](#); [Reines & Volonteri 2015](#); [Suh et al. 2020](#); [Salehirad et al. 2022](#)), we aim to ensure the confident identification of such low-width broad components. For this purpose, we visually inspect 556 AGN candidates that have $\text{FWHM}_{\text{H}\alpha;\text{b}} < 1000 \text{ km s}^{-1}$ (Appendix B).

After a thorough visual inspection, we identify 146 sources exhibiting a clear broad H α component. We consider these, along with the rest of the BL AGN-dominated and composite candidates with $\text{FWHM}_{\text{H}\alpha;\text{b}}$

Table 1. Number of AGN, Composites, and Star-Forming Candidates from the BPT Diagram

	Dwarf ($\log(M_*/M_\odot) \leq 9.5$) Galaxies		High-Mass ($\log(M_*/M_\odot) > 9.5$) Galaxies	
All Sources	221,778		1,128,334	
	NL Candidates	BL Candidates	NL Candidates	BL Candidates
Before Visual Inspection^a				
Line Emitting Galaxies	113,655	841	290,917	5,344
AGN Dominated Sources	350 (0.3%)	55 (6.5%)	21,322 (7.3%)	2,905 (54.4%)
Composites	1,933 (1.7%)	106 (12.6%)	50,330 (17.3%)	1,371 (25.6%)
Star-Forming	111,372 (98.0%)	680 (80.9%)	219,265 (75.4%)	1,068 (20.0%)
After Visual Inspection^b				
AGN Dominated Sources	365 (0.3%)	40 (4.8%)	21,405 (7.4%)	2,822 (53.6%)
Composites	1,951 (1.7%)	88 (10.7%)	50,470 (17.3%)	1,231 (23.6%)

^aThese numbers reflect NL and BL candidates selected based on initial criteria outlined in Section 3.3. The AGN and composite counts are based on the narrow emission-line ratios plotted on the BPT diagram.

^bThese numbers reflect the results after visually inspecting BL candidates with $\text{FWHM}(\text{H}\alpha; b) < 1000 \text{ km s}^{-1}$ that fall in the AGN-dominated and composite regions of the BPT diagram (see Section 4.1.2). Sources failing the visual inspection of broad components remain classified as AGN and composites but are now categorized as NL-AGN sources.

$> 1000 \text{ km s}^{-1}$ as *confident* BL-AGN candidates. Additionally, we classify 154 sources with a statistical broad $\text{H}\alpha$ component, as *tentative* BL-AGN candidates, although their broad components are less clear visually.

Of the remaining 256 visually inspected BL candidates, we identify 252 sources that display a visual second/outflow component in the $[\text{NII}]$ line but are not detected by **EmFit**. We suspect this explains the additional $\text{H}\alpha$ component rather than a true broad component. Additionally, four sources exhibit particularly complex emission line profiles around the $[\text{NII}] + \text{H}\alpha$ emission lines, with multiple overlapping components, preventing us from constraining the presence of a broad component. Consequently, we do not classify these 256 galaxies as BL-AGN and relabel them as NL-AGN. Even though we do not visually inspect any BL candidates that are present on the star-forming branch, it does not affect the percentages reported in Section 4.1.1 or any subsequent analysis in this paper. We present details of our visual inspection in Appendix B.

4.1.3. Final BPT Selection

Of the 296,261 high-mass line-emitting galaxies, we have a final sample of 71,875 NL-AGN and 4,053 BL-AGN high-mass candidates (AGN Fraction $\approx 25.6\%$). These numbers are influenced by the selection criterion of the line-emitting galaxies (Section 3.3). Given that robust detection of emission lines is required for appearing on the BPT diagram, some high-mass quiescent galaxies hosting an AGN may be missed by this

diagnostic. The spectra of quiescent AGN are typically dominated by strong absorption lines from stars, weakening the emission-line contribution from the AGN and resulting in a drop of high-mass AGN candidates detected via the $[\text{NII}]$ -BPT diagram.

Of the 114,496 dwarf line-emitting galaxies, we have a final sample of 2,316 NL-AGN and 128 BL-AGN dwarf candidates (AGN Fraction $\approx 2.1\%$). The majority of dwarf galaxies reside on the star-forming branch. This does not necessarily mean that no AGN is present in these sources. The high star formation in low-mass galaxies can dilute the contribution from AGN (Trump et al. 2015). There might be a few dwarf AGN candidates on the star-forming branch that may be detected via other diagnostics (Molina et al. 2021; Salehirad et al. 2022). In fact, Birchall et al. (2020) found that 85% of their X-ray-confirmed dwarf AGN candidates fail the BPT criterion for AGN. However, the dwarf AGN candidates that are detected from the $[\text{NII}]$ -BPT diagram have been observed to be robust AGN candidates (Reines et al. 2013; Baldassare et al. 2020; Salehirad et al. 2022). We note that we are attempting to detect confident AGN candidates in our sample of galaxies, but do not claim that we are complete. Our estimates therefore provide lower limits to the incidence of AGNs in galaxies. Table 1 provides more detailed information regarding our emission-line classification.

4.2. AGN in Line Emitting Dwarf Galaxies

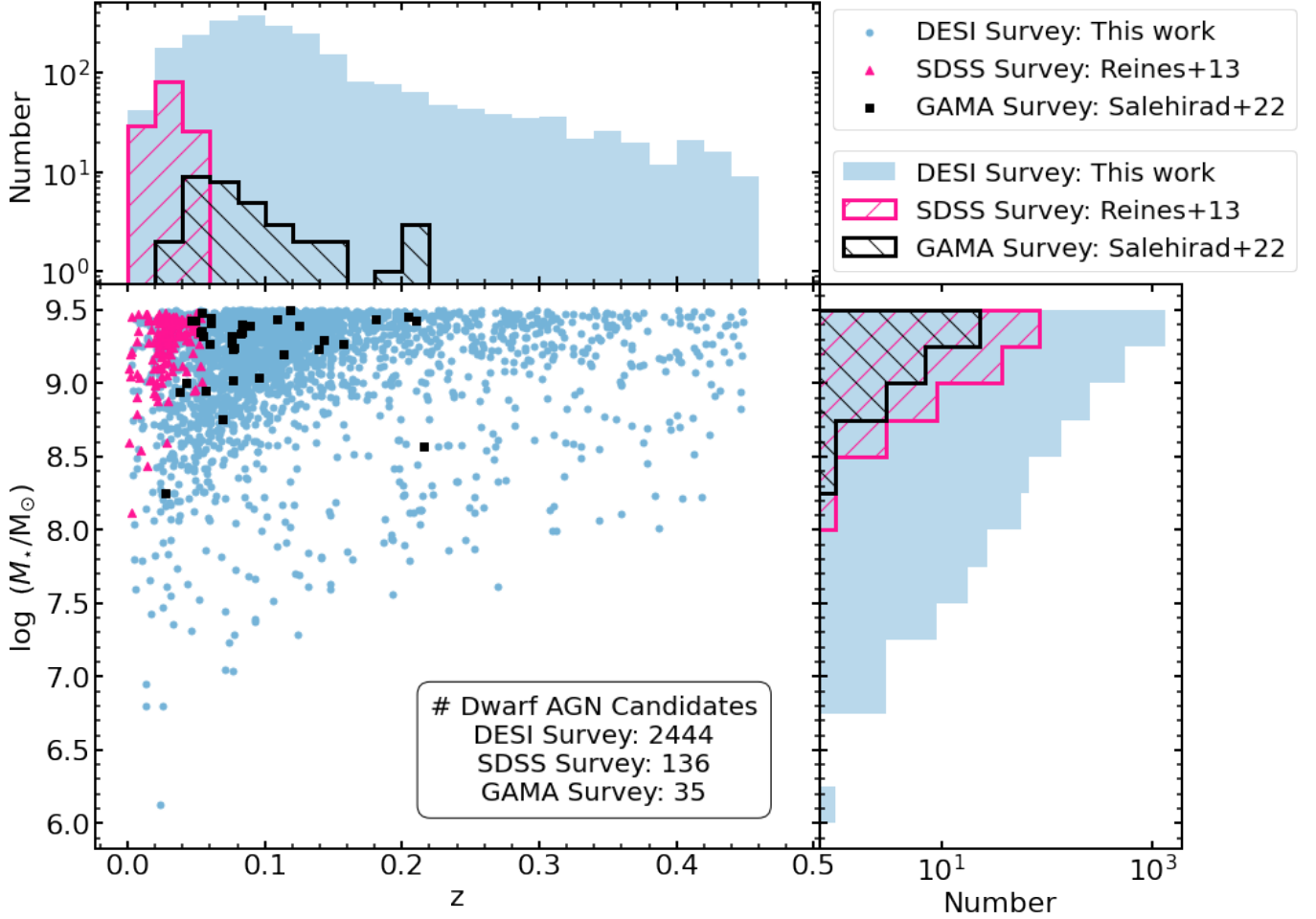


Figure 5. Comparison of dwarf AGN candidates detected from DESI with detections from previous surveys. *Main panel:* Distribution of dwarf AGN candidates in the $\log(M_*/M_\odot) - z$ space. The candidates detected in this paper (from DESI survey) are shown as blue points, while the candidates detected from SDSS and GAMA surveys are shown as pink triangles and black squares, respectively. The number of dwarf AGN candidates detected from each of the surveys is reported on the plot. *Top Panel:* Redshift distribution of the dwarf AGN candidates. *Right Panel:* Stellar mass distribution of the dwarf AGN candidates. The histogram of the candidates in this paper from DESI survey is plotted in blue, while the histograms of the candidates from SDSS and GAMA surveys are shown in hatched pink and hatched black, respectively.

Our result of 2,444 optically selected dwarf AGN candidates more than triples the existing census and is based on using the SV data and only 20% of DESI Year 1 data. By extrapolating to the entire DESI footprint, we expect to conservatively find $\gtrsim 10,000$ dwarf galaxies with detectable AGN signatures within the redshift range of $0.001 \leq z \leq 0.45$, after the completion of the five-year survey.

The observed dwarf AGN fraction in this work ($\approx 2.1\%$) is higher than any previous study using single-fiber integrated optical spectra (AGN fraction $< 1\%$; Reines et al. 2013; Salehirad et al. 2022) or using infrared and X-ray searches (AGN Fraction $< 1\%$; Mezcua et al. 2018; Lupi et al. 2020; Birchall et al. 2020; Latimer et al. 2021b; Birchall et al. 2022; Bykov et al. 2024). In this subsection, we compare our dwarf AGN

candidates with those detected using the BPT diagnostics from prior single-fiber spectroscopic surveys i.e., the Sloan Digital Sky Survey (SDSS; York et al. 2000) and Galaxy and Mass Assembly (GAMA; Driver et al. 2009) survey.

Figure 5 shows the distribution of dwarf AGN candidates in our sample (blue circles), alongside candidates identified by Reines et al. (2013) (with SDSS; pink triangles) and Salehirad et al. (2022) (with GAMA; black squares) in the $\log(M_*/M_\odot) - z$ space. The top and right panels display the distribution of redshift and stellar masses of these samples, respectively. All stellar masses have been estimated using the Chabrier IMF.

Reines et al. (2013) conducted the first systematic search for AGN in dwarf galaxies using the SDSS DR8 spectroscopic catalog (Aihara et al. 2011), covering an

area of $\approx 9200 \text{ deg}^{-2}$. Using the [NII]-BPT emission-line diagnostic, they found 136 candidates with AGN signatures down to $\log(M_*/M_\odot) = 8.1$ and out to $z = 0.055$, with a median $\log(M_*/M_\odot) = 9.3$ and a median redshift of $z = 0.028$. More recently, Salehirad et al. (2022) applied various spectroscopic diagnostics on galaxies from the GAMA DR4 (Driver et al. 2022), spread over an area of $\approx 250 \text{ deg}^{-2}$. They found 35 dwarf AGN candidates down to $\log(M_*/M_\odot) = 7.99$ and out to $z = 0.2$. These candidates have a slightly higher median redshift ($z = 0.077$) compared to Reines et al. (2013), but have a similar median $\log(M_*/M_\odot) = 9.3$.

DESI has greatly expanded the discovery space of optical dwarf AGN candidates. Our candidates extend down to $\log(M_*/M_\odot) \approx 6.12$, almost 1.5 dex lower than both SDSS and GAMA surveys, and also extend out to $z \approx 0.45$. The early DESI data covers a sky area of $\approx 4,400 \text{ deg}^{-2}$, nearly half of the SDSS DR8 coverage ($\approx 9200 \text{ deg}^{-2}$). The larger number of dwarf AGN candidates from our study is partly due to the higher target density of DESI compared to the previous spectroscopic sky surveys. We explore the selection effects compared to Reines et al. (2013) in more detail in Section 6.2.

4.3. AGN Fraction in Galaxies

The fraction of dwarf galaxies hosting a BH, i.e., their BH occupation fraction, is a key diagnostic in understanding the BH seed formation mechanisms (Volonteri 2010; Mezcua 2017). Some of these BHs can be detected as an AGN via different multi-wavelength methods. Therefore, the AGN fraction acts as a lower limit for the BH occupation fraction. We estimate the AGN fraction in DESI sources based on the fraction of galaxies identified as BPT-AGN candidates. As is common in previous optical studies of dwarf galaxies (Reines et al. 2013; Salehirad et al. 2022; Mezcua & Domínguez Sánchez 2020, 2024), we do not directly apply completeness corrections. However, we will consider the effect of accounting for the galaxies that fail the emission line detection criteria from Section 3.3.

To investigate trends with galaxy properties, we start by computing the AGN fraction in line-emitting galaxies in bins of stellar mass and redshift (Figure 6). The size of the squares shown in the figure is proportional to the number of galaxies within those bins, while their color reflects the AGN fraction as shown on the color bar. We find that the BPT-AGN fraction, on average, increases with increasing stellar mass, across the entire redshift range, which is consistent with previous optical emission-line studies (e.g., Juneau et al. 2011). The BPT-AGN fraction is $\lesssim 10\%$ at low stellar masses ($\log(M_*/M_\odot) \leq 9$), and reaches $\approx 100\%$ at high stellar

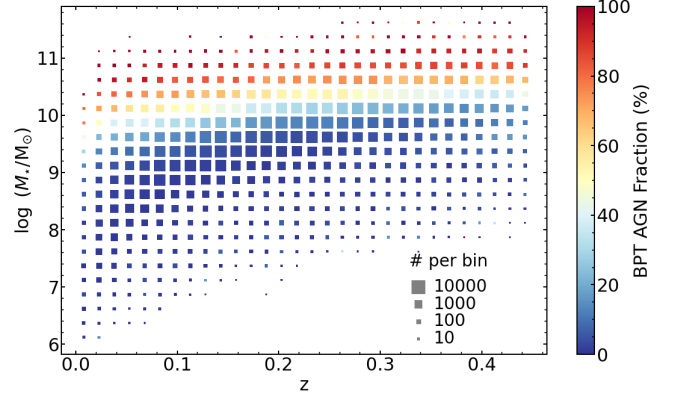


Figure 6. 2D-Distribution of line-emitting galaxies in the $\log(M_*/M_\odot) - z$ space color-coded by the BPT-AGN fraction within the bins. The size of the squares is proportional to the total number of line-emitting galaxies within the bin.

masses ($\log(M_*/M_\odot) \geq 11$). Additionally, we see that at $\log(M_*/M_\odot) \approx 10$, the BPT-AGN fraction decreases with increasing redshift. At lower and higher masses than this region, the change with redshift is unclear. We study the variation of the BPT-AGN fraction with stellar mass and redshift below.

4.3.1. Variation with Stellar Mass

In Figure 7, we show the observed BPT-AGN fraction as a function of stellar mass. We arrange all the sources in order of increasing stellar masses and divide them into bins of nearly equal number of sources ($\approx 54,000$ sources in each bin). We compute two different BPT-AGN fraction estimates: the fraction of BPT-AGN candidates in line-emitting galaxies (shown as red squares in Figure 7); and the fraction of BPT-AGN candidates in all galaxies, including the galaxies without line emission (shown as black circles in Figure 7). Even though some of the non-line-emitting galaxies may host a BH, we assume that they do not host an AGN. Therefore, we are reporting the lower limits of the total BPT-AGN fraction. Within each bin, we compute the median and standard deviation of stellar masses as the representative stellar mass and error. The right panel of Figure 7 is the distribution of BPT-AGN fraction in the low-mass regime. In this case, we divide all the dwarf galaxies into bins of $\approx 27,700$ sources and compute both versions of the BPT-AGN fraction. The horizontal dashed-dotted red line denotes the observed average dwarf AGN fraction in line-emitting galaxies (Section 4.2). This fraction is nearly 4 times higher than the pink dashed line that denotes the average dwarf AGN fraction from Reines et al. (2013).

Focusing on line-emitting galaxies, we observe the BPT-AGN fraction sharply rises from $\approx 1.2\%$ at

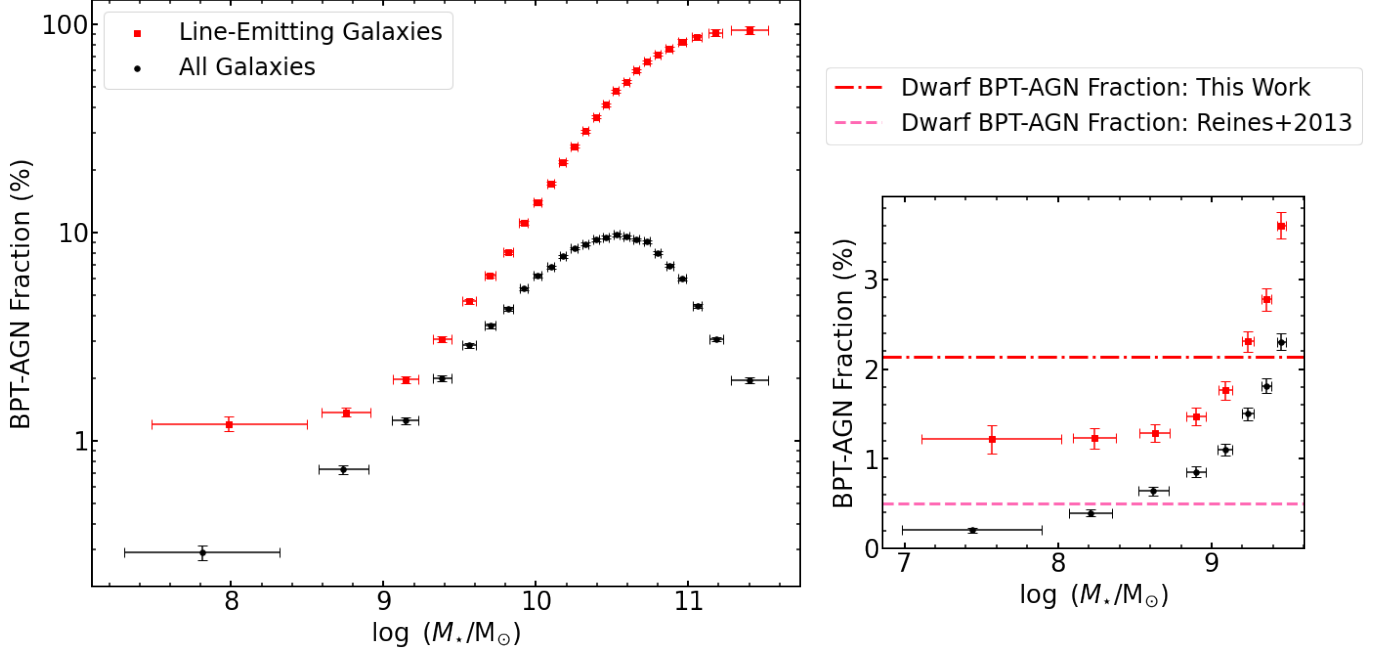


Figure 7. BPT-AGN Fraction as a function of stellar mass: The fraction of BPT-AGN candidates in line-emitting galaxies is shown as red squares, while the fraction of BPT-AGN candidates considering all galaxies is shown as black circles. *Right:* BPT-AGN Fraction as a function of stellar mass in the dwarf galaxy regime. The overall observed BPT-AGN fraction from our study and Reines et al. (2013) are shown as a dashed-dotted red line and dashed pink line, respectively.

$\log(M_*/M_\odot) \approx 8.0$ to $\approx 93.5\%$ at $\log(M_*/M_\odot) \approx 11.4$. While it is well established that nearly all massive galaxies host BHs (Kormendy & Ho 2013), only a subset of these BHs are actively accreting at any given time. Furthermore, strong selection effects are present in this regime, as many sources fail to be detected in all four BPT lines. As a result, there is an increasing bias towards the detection of emission lines linked to the presence of AGN with increasing stellar mass.

At the low-mass end, whether BHs are present at the centers of all dwarf galaxies has not yet been established. The BPT-AGN fraction in dwarf galaxies (right panel of Figure 7) increases from $\approx 1.2\%$ at $\log(M_*/M_\odot) \approx 7.6$ to $\approx 3.6\%$ at $\log(M_*/M_\odot) \approx 9.4$. It drops to $< 2.1\%$ (red horizontal line) by $\log(M_*/M_\odot) \approx 9$, which is the average dwarf AGN fraction. This suggests that the majority of dwarf AGN candidates from the BPT selection criterion are dwarf galaxies with $\log(M_*/M_\odot) > 9$, which is what we see in Figure 6. An important selection bias in this mass regime is that for lower-mass systems, the detected AGN sources are likely accreting at higher Eddington ratios, and hence only the more extreme sources would be selected in dwarf galaxies compared to massive galaxies.

When we include non-line-emitting galaxies that do not have significant emission-line detection (black points in Figure 7), we observe that the BPT-AGN fraction increases from $\approx 0.3\%$ at $\log(M_*/M_\odot) \approx 7.8$, peaks at

$\approx 9.7\%$ at $\log(M_*/M_\odot) \approx 10.5$, turns over and decreases to $\approx 2\%$ at $\log(M_*/M_\odot) \approx 11.4$. The discrepancy between the two estimates of the BPT-AGN fraction is due to the fraction of line-emitting galaxies selected at different stellar masses (see top panel of Figure 8). In the stellar mass range of $9 \leq \log(M_*/M_\odot) \leq 10$, the difference is small, and $> 60\%$ of the sources have strong emission-line detection. However, there is an increase in the divergence between the line-emitting and total BPT-AGN fraction (red and black curves) at higher stellar masses. This divergence occurs because massive galaxies tend to be metal-rich and have weak [OIII] emission (Kauffmann et al. 2003), often failing the selection criterion. In contrast, the differences in the low-mass regime are primarily driven by the [NII] selection criterion, which is expected due to the low metallicity of galaxies in this regime.

The increase in the AGN fraction with increasing stellar mass is similar to some previous studies focusing on the X-ray detected AGN fraction (Mezcua et al. 2018; Birchall et al. 2020). However, other X-ray and multi-wavelength studies have found weak to no variation with stellar mass (Juneau et al. 2013; Birchall et al. 2022, 2023), suggesting that different AGN selection criteria have different selection biases.

4.3.2. Variation with Redshift

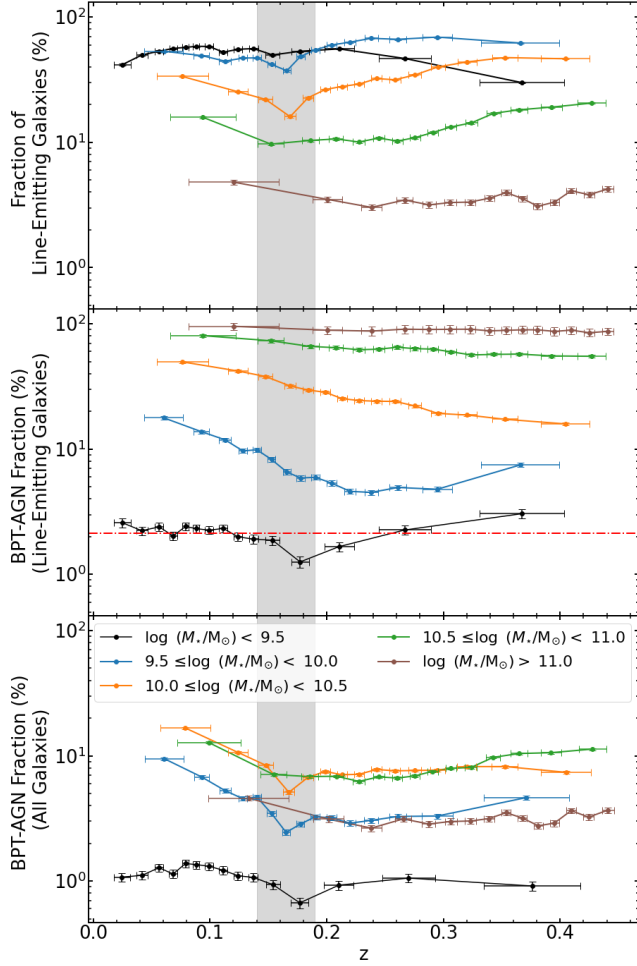


Figure 8. *Top Panel:* Fraction of line-emitting galaxies as a function of redshift; BPT-AGN Fraction as a function of redshift considering only line-emitting galaxies (*Middle Panel*) and considering all galaxies (*Bottom Panel*). In all panels, the fractions in dwarf galaxies are plotted in black, while the massive galaxies are divided into bins of stellar mass. The variation of BPT-AGN fraction with redshift is subject to several selection effects. The red horizontal line in the middle panel denotes the overall observed dwarf BPT-AGN fraction. The shaded gray region denotes the redshift range when the [OIII] emission line coincides with the overlap region of the DESI B and R cameras.

We found that the BPT-AGN fraction strongly depends on the stellar mass. To examine the BPT-AGN fraction as a function of redshift, we group all the dwarf galaxies together and sub-divide high-mass galaxies into stellar mass bins of 0.5 dex. We then organize these sources in increasing order of redshift and calculate the fraction of line-emitting galaxies, as well the line-emitting and total BPT-AGN fractions, within redshift bins that each contain a nearly equal number of sources. The top panel of Figure 8 illustrates the fraction of line-emitting galaxies across different stellar mass selections

as a function of redshift, while the middle and bottom panels display the variations of line-emitting and total BPT-AGN fractions with redshift for these groups, respectively. The horizontal red line in the middle panel is the observed AGN fraction in dwarf galaxies.

A noticeable dip in the estimated fractions is evident in all the panels around $z \approx 0.18$. This dip arises from two issues concerning the [OIII] emission line. In this redshift range, the [OIII] line coincides with the overlap region of the B and R cameras of the DESI spectrograph (shown by grey region in Figure 8), and also one of the skylines (the Na I doublet). As a result, the detection of this emission line becomes very noisy, often resulting in the SNR ([OIII]) failing to meet the selection criterion in this redshift range.

In the dwarf galaxy regime (black line), the fraction of line-emitting galaxies remains relatively constant at $\approx 50\%$ up to $z \approx 0.2$, before declining to $\approx 20\%$ at $z \approx 0.37$. The BPT-AGN fraction for line-emitting dwarf galaxies fluctuates around the overall dwarf AGN fraction ($\approx 2.1\%$; dash-dotted line) and remains nearly constant throughout the entire redshift range. When considering all dwarf galaxies and assuming that the non-line-emitting galaxies do not host an AGN, the BPT-AGN fraction drops to $\lesssim 1\%$ but remains nearly flat with redshift. Thus, the dwarf AGN fraction is almost a factor of two higher when considering only line-emitting galaxies versus all galaxies but with no significant redshift dependency.

When we focus on massive galaxies (colored lines), we find a clear dependence of the trends on stellar mass. As stellar mass increases, the fraction of line-emitting galaxies decreases across all redshifts. Conversely, the BPT-AGN fraction for line-emitting galaxies (middle panel) exhibits an opposite trend and increases with stellar mass across all redshifts. When considering all galaxies (bottom panel), there is no longer a monotonic trend of AGN fraction with stellar mass. However, the trend with redshift behaves similarly between the mass bins: we find that the total BPT-AGN fraction initially decreases, but is nearly constant at $z \gtrsim 0.2$.

Overall, the observed trends are influenced by various selection effects including the emission-line detection at different stellar masses. Moreover, the DESI targeting selection also introduces significant biases (Section 2.1). The BGS sources are uniformly distributed across all stellar masses and redshifts. However, the rest of the high-mass galaxies are predominantly LRG targets, which primarily target high-redshift sources. The SCND targets also include a majority of high-mass and dwarf galaxies in our sample, but their distribution across redshifts is irregular due to different selection criteria (see Fig-

ure 1). These variations in targeting complicate the line-emitting galaxy fraction and BPT-AGN fraction as a function of redshift. Detailed analyses involving selection functions and incompleteness corrections are necessary for a thorough physical interpretation, which we will address in a future publication.

5. BLACK HOLE MASS - STELLAR MASS SCALING RELATION

BH-galaxy scaling relations hold clues about BH seed formation mechanisms and also provide a way to study the co-evolution of BHs and their host galaxies. In this section, we study the $M_{\text{BH}} - M_{\star}$ scaling relation of the BL-AGN candidates and compare it with previous studies.

5.1. Black Hole Masses

The broad $\text{H}\alpha$ emission line can be used to compute BH masses using single-epoch virial techniques. Under the assumption that the BLR gas around the BH is virialized, the kinematics of the gas can be used as a dynamical tracer of BH mass (M_{BH}):

$$M_{\text{BH}} \propto \frac{RV^2}{G}$$

where R is the radius of the BLR around the BH, V is the average velocity of the gas, and G is the gravitational constant. The average velocity of the gas can be inferred using the width of the broad $\text{H}\alpha$ emission line, while the radius of the BLR is approximated using the radius-luminosity relation.

Using the same approach as previous studies (Reines et al. 2013; Reines & Volonteri 2015; Salehirad et al. 2022), we use the Greene & Ho (2005) formula for estimating the BH masses, with the modified radius-luminosity relationship of Bentz et al. (2013) as derived by Reines et al. (2013):

$$\log\left(\frac{M_{\text{BH}}}{M_{\odot}}\right) = \log \epsilon + 6.57 + 0.47 \log\left(\frac{L_{\text{H}\alpha;b}}{10^{42} \text{ erg s}^{-1}}\right) + 2.06 \log\left(\frac{\text{FWHM}_{\text{H}\alpha;b}}{10^3 \text{ km s}^{-1}}\right) \quad (1)$$

where $L_{\text{H}\alpha;b}$ and $\text{FWHM}_{\text{H}\alpha;b}$ are the luminosity and FWHM of the broad $\text{H}\alpha$ component and ϵ is the scale factor, which spans a range of ~ 0.75 – 1.4 (Greene & Ho 2007; Grier et al. 2013, 2017). Here, we assume $\epsilon = 1$ to compare with previous results (Reines & Volonteri 2015).

We compute BH masses based on the **EmFit** measurements of the broad $\text{H}\alpha$ flux and line width (Section 3.2.3)

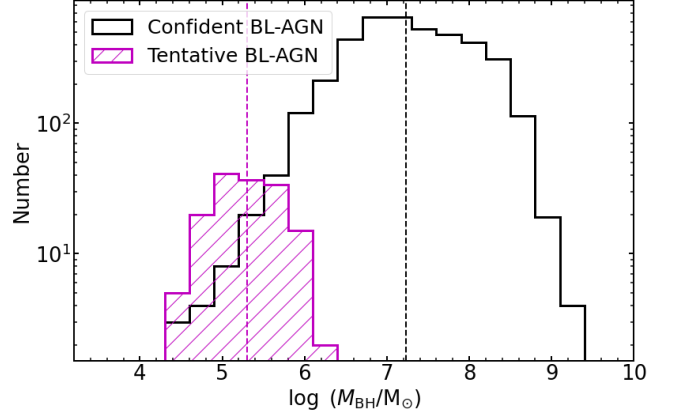


Figure 9. Distribution of BH masses of BL-AGN candidates. The *confident* BL candidates are shown as black histogram, while the *tentative* BL candidates are shown as hatched magenta histogram. The vertical black and magenta lines denote the median BH mass for the confident and tentative candidates, respectively.

and propagate their uncertainties. The median error for our sample of BL-AGN candidates is ≈ 0.02 dex. However, virial BH mass measurements from single-epoch spectroscopy can have several systematic uncertainties on the order of 0.5 dex (McGill et al. 2008; Shen 2013). We therefore add 0.5 dex to our estimated uncertainties in quadrature to get the final uncertainties in M_{BH} .

Figure 9 presents the distribution of BH masses for the 4,027 confident BL-AGN candidates (in black) and 154 tentative BL-AGN candidates (in hatched magenta) from our sample. The BH masses of the confident BL-AGN sources range from $\log(M_{\text{BH}}/M_{\odot}) = 4.4$ to 9.2, with a median of 7.2. On the other hand, the tentative BL-AGN candidates are concentrated at the lower end of the BH mass range, with values between $\log(M_{\text{BH}}/M_{\odot}) = 4.3$ and 6.3, with a median of 5.3.

Among all the BH candidates, 151 confident and 147 tentative BL-AGN candidates have BH masses of $\log(M_{\text{BH}}/M_{\odot}) \leq 6$, identifying them as potential candidates for IMBHs. This constitutes the largest sample of IMBHs identified to date, more than tripling their existing census (Goradzhyanov et al. 2024).

5.2. Dependency on Galaxy Morphology

Combining BH masses (Section 5.1) and host galaxy stellar masses (Section 3.1), we can now build the $M_{\text{BH}} - M_{\star}$ scaling relation. First, we assess whether this relation depends on host galaxy morphology by dividing our sample of BL-AGN based on the TYPE and SERSIC

Of these, 70 IMBH candidates (46 confident and 24 tentative) reside in dwarf galaxies.

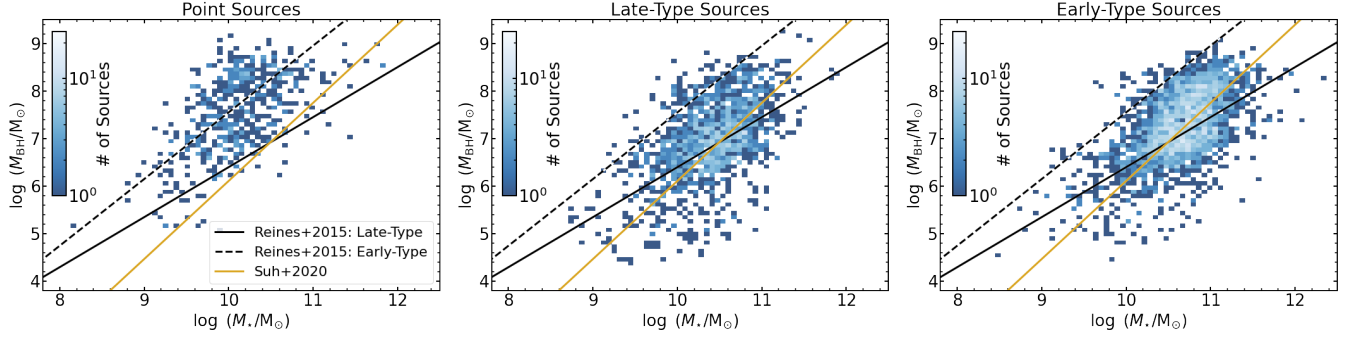


Figure 10. $M_{\text{BH}} - M_{\star}$ scaling relation of BL-AGN candidates with PSF (Left), late-type (Middle), and early-type (Right) host-galaxy morphologies as defined using LS DR9. The color bars denote the number of sources within each bin of the 2D distribution. The empirical fits for late-type and early-type galaxies estimated by Reines & Volonteri (2015) are shown as solid and dashed black lines, respectively. The fit from Suh et al. (2020) is plotted as an orange line.

columns from the LS DR9 catalog (Section 2.2). Point sources are defined based on `MORPHTYPE` = PSF, while the late-type sources are selected if the `MORPHTYPE` is either a round-exponential (REX) or an exponential (EXP) or a Sérsic (SER) with a Sérsic index ≤ 2 . The rest of the candidates that do not have PSF or late-type morphologies are considered early-type galaxies. We show the bivariate distribution of these sources in the $M_{\text{BH}} - M_{\star}$ space in Figure 10, along with the empirical fits by Reines & Volonteri (2015) and Suh et al. (2020).

Reines & Volonteri (2015) studied the $M_{\text{BH}} - M_{\star}$ scaling relation by considering 262 BL-AGNs from SDSS DR8 spectroscopic catalog, 15 reverberation-mapped AGNs from Bentz & Katz (2015), and 79 inactive galaxies with dynamical BH masses from Kormendy & Ho (2013) at $z \leq 0.055$. They identified two distinct fits with different slopes for active and inactive galaxies, which correlate with galaxy morphology. Specifically, the late-type galaxies are located around the fit for active galaxies, while the early-type galaxies align with the fit for inactive galaxies. Building on this, Suh et al. (2020) combined the local AGN sample from Reines & Volonteri (2015) with an additional 100 BL-AGNs from the COSMOS field, extending their analysis to $z \approx 2.5$. They find a comparatively steeper fit, with their high-redshift sample predominantly consisting of high stellar mass ($\log(M_{\star}/M_{\odot}) \gtrsim 11$) and high BH mass ($\log(M_{\text{BH}}/M_{\odot}) \gtrsim 7$) sources.

From Figure 10, we find that the late-type and early-type galaxies occupy similar regions in the $M_{\text{BH}} - M_{\star}$ space, while the point sources lie ≈ 1 dex above them. Both the distributions for $\log(M_{\star}/M_{\odot}) \geq 10$ are consistent with active galaxy fit (late-type fit) from Reines & Volonteri (2015), with the sources with $\log(M_{\text{BH}}/M_{\odot}) \leq 6$ falling below it.

Galaxies with a point source morphology lie toward higher values of BH masses and do not appear to fol-

low the late-type (active) fit from Reines & Volonteri (2015) nor the Suh et al. (2020) fit. However, the early-type galaxy fit from Reines & Volonteri (2015) overlaps with the distribution of these sources. Visual inspection of their spectra reveals quasar-like characteristics, featuring extremely broad emission lines and weak to negligible stellar continuum. This makes their stellar mass estimates highly uncertain. Keeping this limitation in mind, we find that 43 dwarf galaxies with PSF morphologies host BHs with $\log(M_{\text{BH}}/M_{\odot}) \gtrsim 5$. If their stellar masses were accurate or possibly over-estimated, these sources could represent low-redshift counterparts to the over-massive BHs identified by JWST (Harikane et al. 2023; Maiolino et al. 2023; Übler et al. 2023). We discuss this further in Section 6.3.

To analyze and find empirical fits to the $M_{\text{BH}} - M_{\star}$ scaling relation, we exclude the 518 point sources due to the uncertainty with their stellar mass estimates. Given that the rest of the BL-AGN candidates are consistent with the Reines & Volonteri (2015) fit based on active galaxies, we will focus solely on comparing our empirical fit to this late-type (active) fit in the following subsection.

5.3. Empirical Fit to the $M_{\text{BH}} - M_{\star}$ Scaling Relation

We use the 3,633 BL-AGN candidates (3,517 confident and 146 tentative), excluding the point sources, to study the $M_{\text{BH}} - M_{\star}$ scaling relation. Figure 11 shows the bivariate distribution of the confident BL-AGN (left panel) and all BL-AGN sources (including tentative candidates; right panel) in the $M_{\text{BH}} - M_{\star}$ space.

Focusing on confident BL-AGN candidates, we observe a significant spread in BH masses for a given stellar mass (nearly 3 dex at $\log(M_{\star}/M_{\odot}) \approx 10.5$). Compared to previous local measurements of the relation Reines & Volonteri (2015); Greene et al. (2020), the scaling relation now extends to lower galaxy and BH masses, down

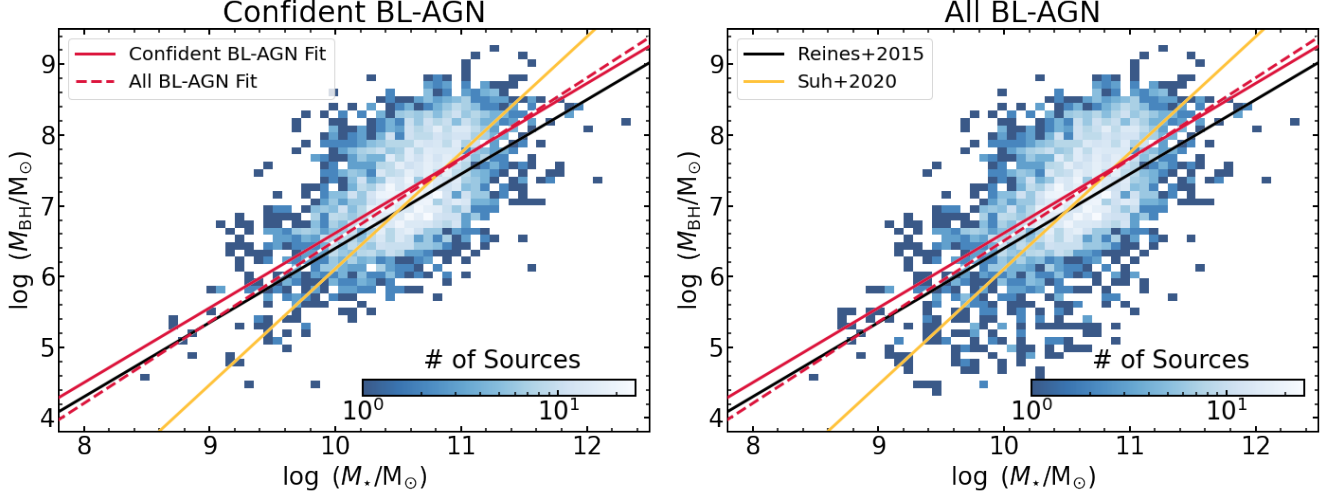


Figure 11. $M_{\text{BH}} - M_{\star}$ scaling relation of *confident* BL-AGN candidates (*Left*) and all BL-AGN candidates (*Right*), excluding point sources. The color bar displays the number of sources within each bin of the 2D distribution. In each of the panels, our empirical fits for confident and all BL-AGN candidates are plotted as solid and dashed red lines, respectively. The fits from Reines & Volonteri (2015) and Suh et al. (2020) are shown as black and orange lines, respectively.

to $\log(M_{\star}/M_{\odot}) \approx 8.5$ and $\log(M_{\text{BH}}/M_{\odot}) \approx 4.4$. When we include the tentative candidates, we also see a similar spread in BH masses at lower mass galaxies (≈ 3 dex at $\log(M_{\star}/M_{\odot}) \approx 9.2$). We find a total of 86 dwarf BL-AGN (64 confident and 22 tentative) candidates, extending up to $z \leq 0.45$. These together represent 5 times more candidates than the 14 low-mass candidates presented in Reines & Volonteri (2015).

To study the correlation between M_{BH} and M_{\star} , and to compare with previous studies, we fit a linear model for the two samples separately, using the Bayesian approach by Kelly (2007). We parametrize the relation similar to Reines & Volonteri (2015), as follows:

$$\log(M_{\text{BH}}/M_{\odot}) = \alpha + \beta \log(M_{\star}/10^{11}M_{\odot}) \quad (2)$$

Considering only the confident BL-AGN candidates, we find:

$$\alpha = 7.67 \pm 0.01; \beta = 1.05 \pm 0.02 \quad (3)$$

When we consider all the BL-AGN candidates, we find:

$$\alpha = 7.66 \pm 0.01; \beta = 1.15 \pm 0.03 \quad (4)$$

We overplot these fits as solid and dashed red lines, respectively, in Figure 11. We see that including the tentative candidates leads to a slightly steeper slope but with a similar normalization compared to the fit with only confident candidates. We find that our fits exhibit

a similar slope but a higher normalization compared to the Reines & Volonteri (2015) fit (black line). In contrast, the fit from Suh et al. (2020) (orange line) has a steeper slope relative to both our fit and the Reines & Volonteri (2015) fit. The primary divergence arises from the high-mass end, which is influenced by selection biases. Specifically, Suh et al. (2020) focuses on massive BHs selected based on their strong X-ray emission and extremely broad $\text{H}\alpha$ lines, while Reines & Volonteri (2015) do not include such sources in their sample. The closest counterparts of such sources in our sample are the point sources that have high BH masses (left panel of Figure 10) and have been excluded from our bestfit.

Excluding the point sources removes candidates with potentially over-massive BHs that are being ubiquitously discovered at high redshifts by JWST (Harikane et al. 2023; Maiolino et al. 2023; Greene et al. 2024). However, we find potential under-massive BHs near $9 \leq \log(M_{\star}/M_{\odot}) \leq 11$ and $4.4 \leq \log(M_{\text{BH}}/M_{\odot}) \leq 6$ (right panel of Figure 11). This scenario is possible if the BH growth is inefficient or delayed in these galaxies. The presence of star formation in low-mass galaxies can stunt the growth of BHs due to supernova feedback heating the gas and inhibiting accretion. This feedback can further hinder the gas from getting to the nuclear

If we assume the stellar masses of these point sources are accurate, we find a fit consistent with that of the confident candidates ($\alpha = 7.66 \pm 0.01; \beta = 1.02 \pm 0.03$). However, if some of the stellar masses of these point sources are underestimated, by more than 1 dex, this could potentially lead to a steeper fit that aligns more closely with the Suh et al. (2020) fit.

regions as a result of the low gravitational potential of these sources (Dubois et al. 2015; Byrne et al. 2023). A possibility for such under-massive BHs in massive galaxies may be associated with recent mergers, where an SMBH is merging with a lower-mass BH (Kelley 2021). In such instances, the lower-mass BH could be undergoing accretion (D’Orazio & Charisi 2023), causing us to observe the broad H α component from its BLR kinematics. The main uncertainty in these sources comes from the intrinsic difficulty in differentiating whether the line widths are due to AGN or outflows (Appendix B). However, excluding or including them does not significantly affect our fit.

While the extension of the $M_{\text{BH}} - M_{\star}$ scaling relation to lower galaxy masses may provide clues regarding the origin of BH seeds (Mezcua 2017; Volonteri 2010), it can also point to the variations in the modes of accretion in galaxies (Ricarte & Natarajan 2018). We explore this connection of the scaling relation with theoretical models in Section 6.3.

6. DISCUSSION

In this section, we examine how our main results on the AGN fraction in dwarf galaxies, BH masses, and the $M_{\text{BH}} - M_{\star}$ scaling relation may be impacted by our choices and assumptions. We describe our reasoning for using only the [NII]-BPT diagram in Section 6.1. We investigate the higher dwarf AGN fraction observed from DESI compared to SDSS in Section 6.2. Finally, we compare our $M_{\text{BH}} - M_{\star}$ scaling relation and its relation to the BH seed formation models in Section 6.3.

6.1. [SII]-BPT Diagram

The [NII]-BPT diagram is a valuable diagnostic for selecting AGN-dominated sources, but it is metallicity sensitive (Storchi-Bergmann et al. 1998; Carvalho et al. 2020). This may be problematic for dwarf galaxies, which generally have low metallicities. As a result, low-metallicity star-forming and AGN dwarfs can occupy the same region as low-mass starbursts.

Apart from the [NII]-BPT diagram, two other emission-line diagnostics are often used in identifying AGN signatures in galaxies: [SII]/H α vs. [OIII]/H β ([SII]-BPT Diagram) and [O I]/H α vs. [OIII]/H β ([O I]-BPT Diagram). These two diagnostics reduce the effect of metallicity and separate the star-forming galaxies from AGN-dominated Seyferts and low-ionization nuclear-emitting regions (LINERs). Polimera et al. (2022) revised the AGN selection criterion in dwarf galaxies using [NII], [SII], and [O I]-BPT diagrams. They included a new class of dwarf galaxies, the star-forming AGN (SF-AGN) that lie on the star-forming branch in

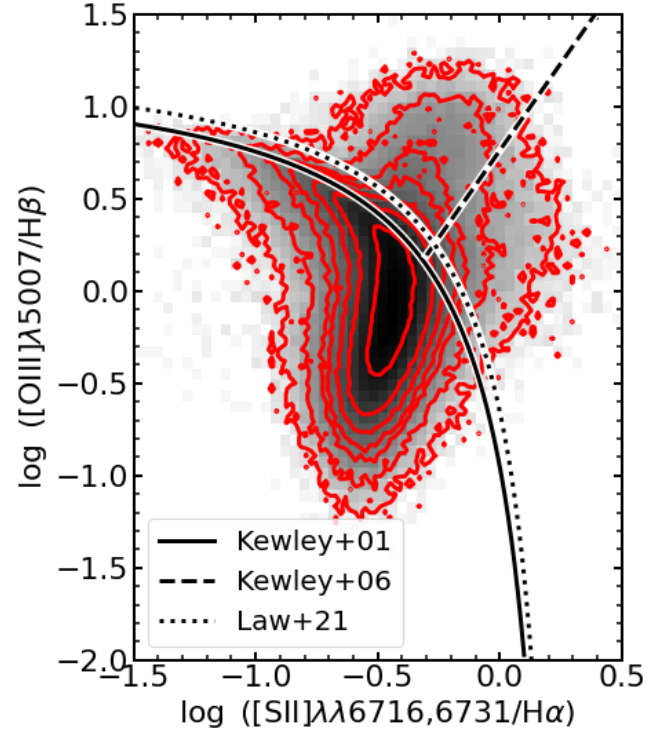


Figure 12. [SII]-BPT Diagram of all the sources in our sample that pass the required criteria (see text). The contours of the source density distribution are shown in red. The solid black line is from Kewley et al. (2001) that separates the star-forming galaxies from Seyferts/LINERs. The dashed black line is from Kewley et al. (2006) that separates the Seyferts from LINERs. The new demarcation line that separates the star-forming sources from Seyferts/LINERs by Law et al. (2021) is shown as a dotted black line.

the [NII]-BPT diagram, but are Seyferts/LINERs from [SII] or [O I]-BPT diagrams. Using this new classification scheme for dwarf galaxies, they find an AGN fraction, ranging from $\approx 3\%$ to $\approx 16\%$ depending on the catalog used. More recently, Mezcua & Domínguez Sánchez (2024) also found a higher AGN fraction $\approx 20\%$ when combining all three diagnostic diagrams. However, the validity of the current demarcation lines is unclear and there have been several efforts to improve them (Ji & Yan 2020; Law et al. 2021). In this subsection, we examine the demarcation lines used for the [SII]-BPT diagrams.

We start with the 1,350,112 sources in our sample with robust stellar masses and emission-line measurements in the redshift range of interest (Section 3). We apply the following SNR and AoN cuts on the four emission lines required for the [SII]-BPT diagram:

$$\begin{aligned} \text{SNR} &\geq 3 \text{ for } [\text{SII}], \text{H}\alpha, [\text{OIII}] \\ (\text{SNR} &\geq 1) \text{ \& } (\text{AoN} \geq 1) \text{ for } \text{H}\beta \end{aligned}$$

These cuts result in 449,295 sources with $\log(M_*/M_\odot) \geq 6.0$. Figure 12 shows the [SII]-BPT diagram of all these sources. The solid black lines in the figure denote the demarcation line for separating the star-forming sources from the AGN-dominated Seyferts and LINERs (Kewley et al. 2001). The dashed black line separates Seyferts (left of the line) and LINERs (right of the line) (Kewley et al. 2006). These lines are traditionally used in AGN-related studies (Polimera et al. 2022; Salehirad et al. 2022; Mezcuca & Domínguez Sánchez 2024). A new demarcation line put forth by Law et al. (2021) is shown by the dotted black line. They used line-of-sight velocity distributions of MaNGA sources to constrain the dynamical properties of the ionized gas and provided new demarcation lines for all three BPT diagrams.

From Figure 12, we see that the density of sources in the star-forming branch (dense black region) extends beyond the solid black line. In particular, the density contours on the top-left corner that overlap the star-forming branch extend above the demarcation line by Kewley et al. (2001) and are instead more consistent with the Law et al. (2021) demarcation line. This finding suggests that the demarcation line needs to be revised for the [SII]-BPT diagnostic.

By considering the Kewley et al. (2001) line, we find 55,208/449,295 AGN candidates (AGN Fraction $\approx 12.3\%$). However, if we consider the Law et al. (2021) line, we identify 27,953/449,295 AGN candidates (AGN Fraction $\approx 6.2\%$), nearly half of the traditional diagnostic. When we focus on dwarf galaxies, the AGN fraction changes dramatically from 17.4% with the Kewley et al. (2001) line to just 4.6% with the Law et al. (2021) line. This stark difference highlights that the AGN fraction is sensitive to the chosen diagnostic line. This could explain the unusually high dwarf AGN fraction in dwarf galaxies reported by Polimera et al. (2022) compared to other single-fiber spectroscopic studies. Some galaxies near these demarcation lines may exhibit both star formation and AGN activity. Therefore, careful analysis is essential for accurately estimating the AGN fraction using these diagnostic methods.

To identify AGN signatures in galaxies and facilitate comparisons with similar studies, especially in the dwarf galaxy regime, we utilize the [NII]-BPT diagram in this paper, while deferring the analysis of the other two diagnostics for future publications. Even with just this single diagnostic, we identify a robust sample of dwarf AGN candidates (Section 4.1). Incorporating the other two diagnostics will likely reveal an even higher dwarf AGN fraction than what we observed in this study.

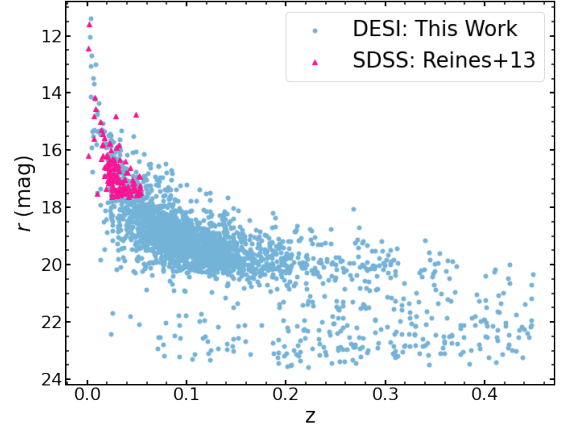


Figure 13. Distribution of dwarf AGN candidates from this work (shown as blue circles) and from Reines et al. (2013) (shown as pink triangles) in the $r - z$ space.

6.2. Dwarf AGN Fraction: DESI vs. SDSS

Using the [NII]-BPT diagnostic, Reines et al. (2013) reported a dwarf AGN fraction of $\approx 0.5\%$ based on SDSS DR8 spectroscopic data, which utilized the original SDSS spectrograph. Applying the same diagnostic on the early DESI data, our study reveals a dwarf AGN fraction of $\approx 2.1\%$ (Section 4.2), nearly four times higher than this previous estimate. We investigate possible explanations for this increased fraction, such as differences in target selection or instrumental characteristics (e.g., aperture size, spectral resolution). We begin by comparing the targets from both surveys, followed by building a matched sample between SDSS and DESI to isolate the impact of the instrument design.

The DESI targets probe fainter sources than the SDSS targets. Figure 13 compares dwarf AGN candidates from our study (shown as blue circles) with those identified by Reines et al. (2013) (shown as pink triangles) in the $r - z$ space. Our candidates reach approximately 2.5–5 magnitudes fainter and extend about 10 times further in redshift compared to the Reines et al. (2013) sample.

To facilitate a direct comparison, we create matched samples of galaxies with similar redshift and r magnitudes to compare DESI vs. SDSS spectra. For this purpose, we first recreate the starting sample of Reines et al. (2013) using the NASA-Sloan Atlas (NSA). By applying the same selection criteria outlined in their paper, we identify 24,966 dwarf galaxies. To establish a common photometric selection, we cross-match these

This number differs slightly from the 25,974 sources reported by Reines et al. (2013)

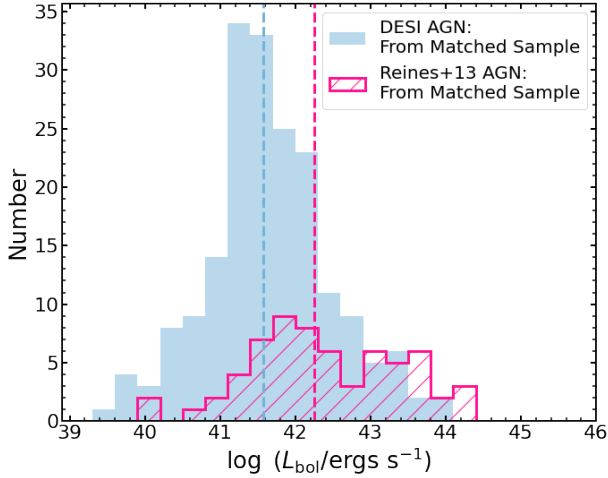


Figure 14. Distribution of AGN bolometric luminosities of the dwarf AGN candidates from the matched starting sample between DESI and SDSS. The filled blue histogram shows the dwarf AGN candidates from DESI, while the hatched pink histogram shows the dwarf AGN candidates from SDSS. The vertical blue and pink lines denote the median $\log(L_{\text{bol}}/\text{ergs s}^{-1})$ values of these distributions.

galaxies with the LS DR9 catalog, focusing on sources brighter than the SDSS magnitude limit of $r < 17.7$ mag. We obtain 21,468 dwarf galaxies including 123 candidate AGN, which results in an AGN fraction of $\approx 0.6\%$ based on the SDSS spectra, in agreement with Reines et al. (2013).

We check the available sample size spanning the same parameter space of $r < 17.7$ mag and $z \leq 0.055$. The number of DESI targets (4,999 sources) within those limits is smaller than the SDSS targets (21,468 sources). Consequently, we identify up to three potential SDSS sources for each DESI target by locating the nearest neighbors in the $r - z$ space. Some DESI sources have only one closest neighbor, resulting in 4,798 unique DESI sources with a total of 10,478 SDSS neighbors.

To validate our matched sample, we perform the Kolmogorov – Smirnov (K-S test) on r and z distributions of these sub-samples, yielding a p -value of 0.99 and 1.0, respectively. These high values indicate that the matched samples have similar distributions in both r and z . We identify 189/4,798 dwarf AGN candidates (AGN Fraction $\approx 3.9\%$) from DESI and 64/10,478 dwarf AGN candidates (AGN Fraction $\approx 0.6\%$) from SDSS. This difference in AGN fraction is even more pronounced, increasing from a factor of 4 to nearly 8 for the matched DESI sample compared to the SDSS-matched sample. This suggests that the DESI target selection does not account for the observed higher AGN fraction.

We now focus on the differences in instrument properties. The DESI spectrograph offers higher spectral resolution ($60 - 150 \text{ km s}^{-1}$) compared to the SDSS spectrograph ($100 - 190 \text{ km s}^{-1}$). We note that the SDSS resolution is already sufficient to isolate the emission lines used in the BPT diagram and to resolve the profile of $\text{H}\alpha$ in case of broad components. Nevertheless, it is plausible that a higher spectral resolution can lead to a more efficient detection of faint emission lines. Additionally, DESI fibers have a smaller diameter ($1.5''$) compared to SDSS fibers ($3''$). Since AGNs are typically located at the centers of galaxies, the smaller fiber size of DESI captures light primarily from this central AGN, thereby reducing contamination from the surrounding galaxy and minimizing dilution from star formation (Trump et al. 2015). We examine these scenarios by comparing the spectra obtained for the same galaxies from the two surveys.

We perform a positional cross-match between the 21,468 dwarf galaxies from SDSS and our starting sample of dwarf galaxies and find 1,725 common candidates. Among these, we find 9 dwarf AGN candidates from Reines et al. (2013), while our analysis reveals a total of 24 dwarf AGN candidates. Of the 9 AGN candidates from SDSS, five are also classified as AGN by our selection, two are classified as star-forming, and two do not meet our SNR criteria. In addition to the five common dwarf AGN candidates, we identify 19 additional candidates not selected as AGN by Reines et al. (2013). We visually inspect the DESI spectra and fits of these 19 candidates and confirm that they are valid AGN candidates. Given that the SDSS spectra still detect the emission lines (even if the sources lie on the star-forming branch of the BPT), we conclude that spectral resolution or depth is unlikely to be the primary factor. Instead, we suspect that the smaller fiber size of DESI plays a significant role in detecting a higher number of dwarf AGN candidates compared to SDSS, thereby contributing to the observed increase in the dwarf AGN fraction.

In fact, Moustakas et al. (2010) demonstrated that the fraction of AGN in a galaxy sample is strongly influenced by the integrated light collected within the spectroscopic aperture (see Table 5 and Figure 5). More recently, Albán & Wylezalek (2023) also found that the number of detected AGN candidates decreases as the aperture size increases. If our supposition is correct, we further expect that a smaller aperture would facili-

However, some studies using the MaNGA IFU have reported AGN ionization signatures from wandering and off-nuclear BHs that are often missed by single-fiber spectroscopy (e.g. Wylezalek et al. 2018; Mezcuá & Domínguez Sánchez 2020, 2024).

tate the detection of less luminous AGNs by effectively isolating their emission from those of the surrounding star-forming regions.

We estimate the bolometric luminosities (L_{bol}) of all the dwarf AGN candidates from the matched samples using the [OIII] luminosity, following the formula ($L_{bol} = L_{[OIII]} \times 1000$) from Moran et al. (2014). For the 64 candidates from SDSS, the $\log(L_{bol}/\text{ergs s}^{-1})$ values range from 40.0 – 44.2, with a median of 42.2. In contrast, the $\log(L_{bol}/\text{ergs s}^{-1})$ values for the 189 DESI dwarf AGN candidates span from 39.3 – 44.0, with a median of 41.6, ≈ 0.6 dex lower than the SDSS candidates.

Figure 14 shows the distribution of the $\log(L_{bol}/\text{ergs s}^{-1})$ values for DESI (in blue) and SDSS (in pink). The lower number of DESI sources at higher luminosities can be attributed to the 1:3 selection ratio of the matched sample. However, as the figure indicates, DESI recovers a greater overall number of AGN candidates compared to SDSS. We perform the K-S test on these luminosities and obtain a p -value of $\approx 1.4 \times 10^{-5}$, suggesting that the luminosity distributions for the two samples are significantly different. This indicates that DESI effectively probes lower luminosity AGN candidates compared to SDSS within the same $r - z$ range, further supporting our hypothesis that the aperture size is indeed the dominant effect driving the difference in the dwarf AGN fraction.

6.3. BH Seed-Formation Mechanisms

The presence of AGN in dwarf galaxies and the Intermediate-Mass Black Holes (IMBHs) that power them hold clues to the origin of SMBHs in the early Universe. In this subsection, we explore our results of the $M_{BH} - M_*$ scaling relation in the context of available literature regarding BH seed formation models.

Early BH seeds can be broadly divided into two types depending on their initial mass (Mezcua 2017; Greene et al. 2020): 1) *Light* seeds ($M_{BH} \approx 10^2 - 10^3 M_\odot$) that form as end products of Population III stars in the early Universe (“Pop-III scenario”); 2) *Heavy* seeds ($M_{BH} \approx 10^4 - 10^6 M_\odot$) that form when pristine gas in the early Universe directly collapses into a BH instead of undergoing fragmentation to form stars (“Direct Collapse scenario”). As we cannot directly observe their formation with our current telescopes, we focus on their imprints in the local universe. Most of these early BHs grow via accretion and mergers to the SMBHs that we see today. But, a fraction of these might be left over in isolated galaxies and we expect them to be observed as IMBHs in local dwarf galaxies.

Theoretical studies propose that the low-mass end of the $M_{BH} - \sigma_*$ relation can help differentiate between

these BH seed formation models (Volonteri & Natarajan 2009; Volonteri 2010). While these studies specifically examine the correlation between the BH mass and stellar velocity dispersion, the expected correlations are likely similar to the relationship between BH mass and stellar mass. If the initial BHs are heavy seeds, the scaling relation is predicted to flatten at the low-mass end. Conversely, if the initial seed BHs are light seeds, the scaling relation from higher-mass galaxies is expected to extend down to lower masses. This is based on the assumption that the observed black holes in local dwarf galaxies represent remnant seed black holes from the early universe, which experienced minimal evolution.

From Figure 11, we observe that our scaling relation extends down to $\log(M_*/M_\odot) \approx 8.5$, with no evident flattening in the relation. The spread among low-mass galaxies appears similar to that of high-mass galaxies. Given that our candidates reach down to $\log(M_{BH}/M_\odot) \approx 4.4$, with most residing below the established relation, these results may suggest a Population-III seed-formation scenario. Despite their uncertain stellar masses, incorporating the point sources from Figure 10 could provide additional insights into this relation. If the stellar masses of these sources are accurate, their distribution is consistent with our confident candidates. Also, if their stellar masses are underestimated, they would shift to the right on the plot, likely aligning with our empirical relation or the one proposed by Suh et al. (2020). Conversely, if their stellar masses are over-estimated, they might represent over-massive BHs in dwarf galaxies. In this case, it could lead to a flattening of the $M_{BH} - M_*$ relation, suggesting a direct collapse seed-formation scenario.

High-redshift observations using JWST have identified $\gtrsim 20$ over-massive BHs pointing to a direct collapse scenario (Harikane et al. 2023; Maiolino et al. 2023; Übler et al. 2023; Greene et al. 2024). However, these observations are affected by selection biases favoring the brightest AGN and are likely not detecting the faint sources hosting light seed BHs. Moreover, using a new suite of cosmological simulations, Bhowmick et al. (2024) suggest that it may be possible to grow these high-redshift over-massive BHs from light seeds with efficient mergers.

Ricarte & Natarajan (2018) argued that the low-mass end of the $M_{BH} - \sigma_*$ scaling relation is driven primarily by the accretion modes of BHs and not the seed-formation models. Furthermore, they show that a hybrid seed-formation model with both light and heavy seeds is almost indistinguishable from a light seed model when studying the scaling relations. Regan & Volonteri (2024) also emphasized that both seed formation scenarios can occur simultaneously. They suggest that rather

than a bimodal distribution of light and heavy seeds, there exists a continuum of BH seeds with the light seeds more abundant and the heavier seeds becoming rarer.

The increased census of dwarf AGN candidates from this study over a spread of BH masses provides an avenue to study the accretion modes in these sources. This number will increase with future DESI releases and will begin the era of the statistical study of dwarf galaxies and their central BHs. Multi-wavelength observations, including future releases of eROSITA X-ray data (Predehl et al. 2021; Sacchi et al. 2024), will be useful in constraining the low-mass end of the galaxy-BH scaling relations and their connection to the BH seed formation models.

7. CONCLUSIONS

Using early DESI spectroscopic data from DESI EDR and 20% of Year 1 (DA0.2), we identify AGN in a sample of 1,385,177 galaxies split into dwarf ($\log(M_*/M_\odot) \leq 9.5$) and high-mass ($\log(M_*/M_\odot) > 9.5$) galaxies. We also constrain the $M_{\text{BH}} - M_*$ scaling relation to lower galaxy and BH masses compared to previous studies. We use the photometric data from LS DR9 to estimate stellar masses with the SED fitting code CIGALE (Section 3.1, Siudek et al. 2024). We develop a Python-based emission-line fitting code, **EmFit**, to measure the fluxes and widths of narrow and broad components of various emission lines. By selecting line-emitting galaxies at $z \leq 0.45$ across the stellar mass range, we conclude the following:

- Using the optical emission-line [NII]-BPT diagnostic, we find 75,928/296,261 ($\approx 25.6\%$) high-mass AGN candidates and 2,444/114,496 ($\approx 2.1\%$) dwarf AGN candidates. With these sources, we have more than tripled the existing census of optical dwarf AGN candidates (Section 4).
- DESI has significantly expanded the discovery space for dwarf AGN candidates. We have extended the search to ≈ 1.5 dex lower galaxy masses and up to 10 times higher redshifts compared to previous spectroscopic surveys (Figure 5). The full DESI survey, set to be completed by 2026, will extend the sample size to $\gtrsim 10,000$ dwarf AGN candidates.
- Our estimation of the dwarf BPT-AGN fraction ($\approx 2.1\%$) is nearly four times higher than that from a comparable systematic search using SDSS (Reines et al. 2013). This increase can be primarily attributed to the smaller fiber size of DESI compared to SDSS, which aids with the identifica-

tion of lower luminosity AGN within the same magnitude and redshift range (Section 6.2).

- We find that the BPT-AGN fraction in line emitting galaxies increases with increasing stellar mass, from $\approx 1.2\%$ at $\log(M_*/M_\odot) \approx 8.0$ to $\approx 93.5\%$ at $\log(M_*/M_\odot) \approx 11.4$. On average, the BPT-AGN fraction slightly decreases with increasing redshift. However, these trends are affected by selection effects including stellar mass variations, emission line detection limits, and DESI targeting algorithms (Section 4.3).
- Of the 410,757 line-emitting galaxies in our sample, 6,185 ($\approx 1.5\%$) sources show a broad H α component. Using the [NII]-BPT diagnostics, we have a sample of 4,181 BL-AGN candidates that are likely powered by an AGN (Section 4.1).
- We estimate the BH masses of the BL-AGN candidates using the flux and width measurements of the broad H α component. The BH masses extend down to $\log(M_{\text{BH}}/M_\odot) \approx 4.4$ for confident BL-AGN candidates and to $\log(M_{\text{BH}}/M_\odot) \approx 4.3$ for tentative candidates. Among these, we find 151 confident (and 147 tentative) BL-AGNs have $M_{\text{BH}} \leq 10^6 M_\odot$, making this the largest sample of IMBH candidates to date (Section 5.1).
- We extend the $M_{\text{BH}} - M_*$ scaling relation down to $\log(M_*/M_\odot) \approx 8.5$ and $\log(M_{\text{BH}}/M_\odot) \approx 4.4$ (Figure 11). The empirical fit from these sources has a similar slope to Reines & Volonteri (2015), but a slightly higher normalization (Section 5.3).
- The majority of the tentative candidates lie below the empirical fit, suggesting that these sources host under-massive BHs assuming that their broad lines from BLR kinematics. This could be due to the low efficiency of BH growth in galaxies (Section 5.3).

The anticipated increase in the sample of dwarf AGN candidates over the next five years with DESI will accelerate studies of AGN in dwarf galaxies. This expansion will enhance the identification of AGN candidates at the low-mass end of the $M_{\text{BH}} - M_*$ scaling relation, thereby providing insights into BH seed formation. The statistical sample of dwarf AGN candidates will be invaluable for addressing several key questions related to galaxy evolution on the smallest scales, including accretion modes in low-mass galaxies and the co-evolution of galaxies and their central BHs.

DATA AVAILABILITY

All the data from the figures are available in machine-readable form at <https://doi.org/10.5281/zenodo.14009453>.

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[desi.lbl.gov/collaborating-institutions](https://www.desi.lbl.gov/collaborating-institutions). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U. S. National Science Foundation, the U. S. Department of Energy, or any of the listed funding agencies.

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APPENDIX

A. DOUBLE-PEAKED EMISSION LINE SOURCES

When fitting narrow emission lines ([SII] and [OIII]), we test for extra components as mentioned in Section 3.2. These extra components can be an outflow component (Figure 2) or an extra narrow component. Figure 15 shows an example of a double-peaked emission line candidate that requires two components to fit all the narrow lines: H β , [OIII], [NII], H α , and [SII]. Such double-peaked emission lines can be a result of complex gas kinematics (e.g., double nuclei, accretion disk kinematics, ejecta, bar) in the galaxy (e.g., [Maschmann et al. 2023](#)). In the case of two physically associated narrow components, their fluxes may need to be combined to study the ionization signatures in the galaxy. Our methodology to identify these sources is described below.

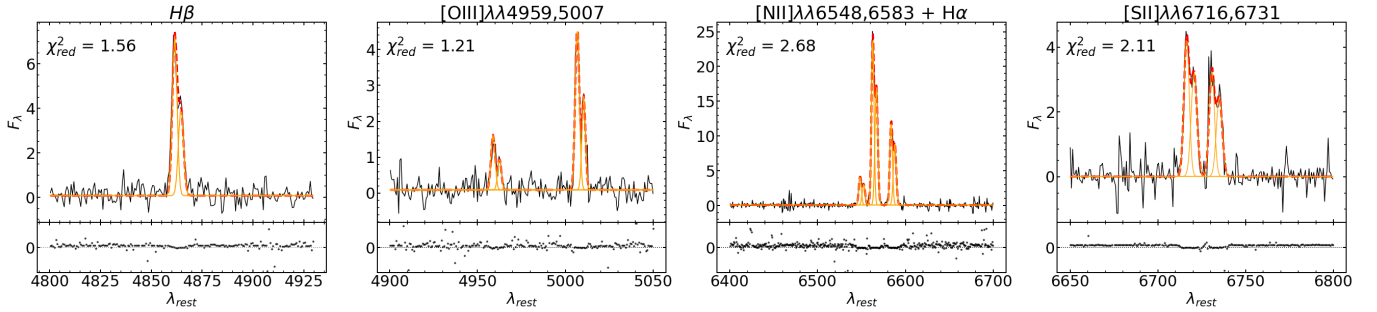


Figure 15. Best-fit model example of a double-peaked emission line candidate (DESI J86.0033-22.4275): The best-fit models to the continuum-subtracted emission-line spectrum in the regions - H β , [OIII], [NII] + H α , and [SII] - from left to right. The spectrum is shown in black, while the best-fit models are shown in dashed red. The individual narrow and extra components are plotted in orange. The reduced χ^2 values for each fit are given in the upper left corner of the individual panels. The fractional residuals are plotted as gray points in the bottom panels for the fits.

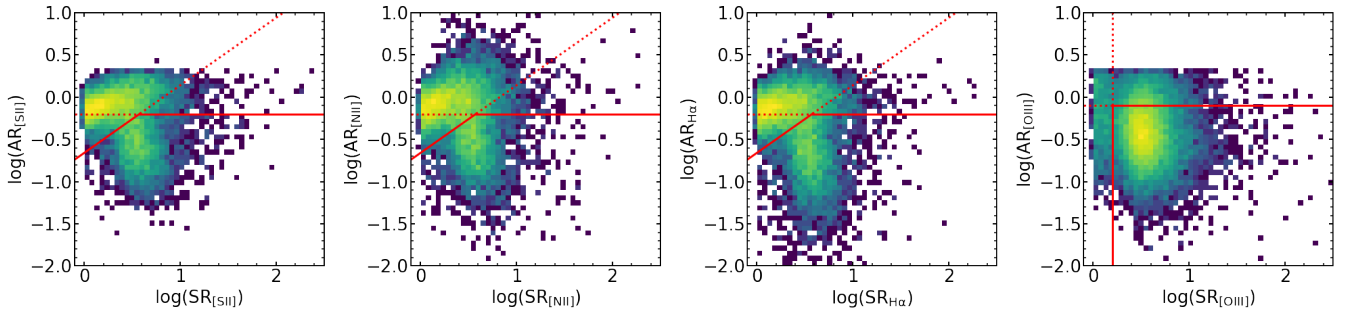


Figure 16. Bivariate distribution of sources in the Amplitude ratio - σ ratio space for [SII], [NII], H α , and [OIII] - from left to right. Only the sources with two components from the fitting method are plotted. The solid red lines denote the selection criteria for separating the fits with outflow components from the fits with extra narrow components.

For the double-peaked emission lines, we find that either the amplitudes or the widths of the two components are similar. This is in contrast with the outflows for which the width and amplitude of the two components are distinct. We define the amplitude ratios and σ ratios of the two components for each of the emission lines as follows:

$$\text{AR}_{\text{em}} = \frac{\text{Amplitude}_{\text{em;out}}}{\text{Amplitude}_{\text{em}}}$$

$$\text{SR}_{\text{em}} = \frac{\sigma_{\text{em;out}}}{\sigma_{\text{em}}}$$

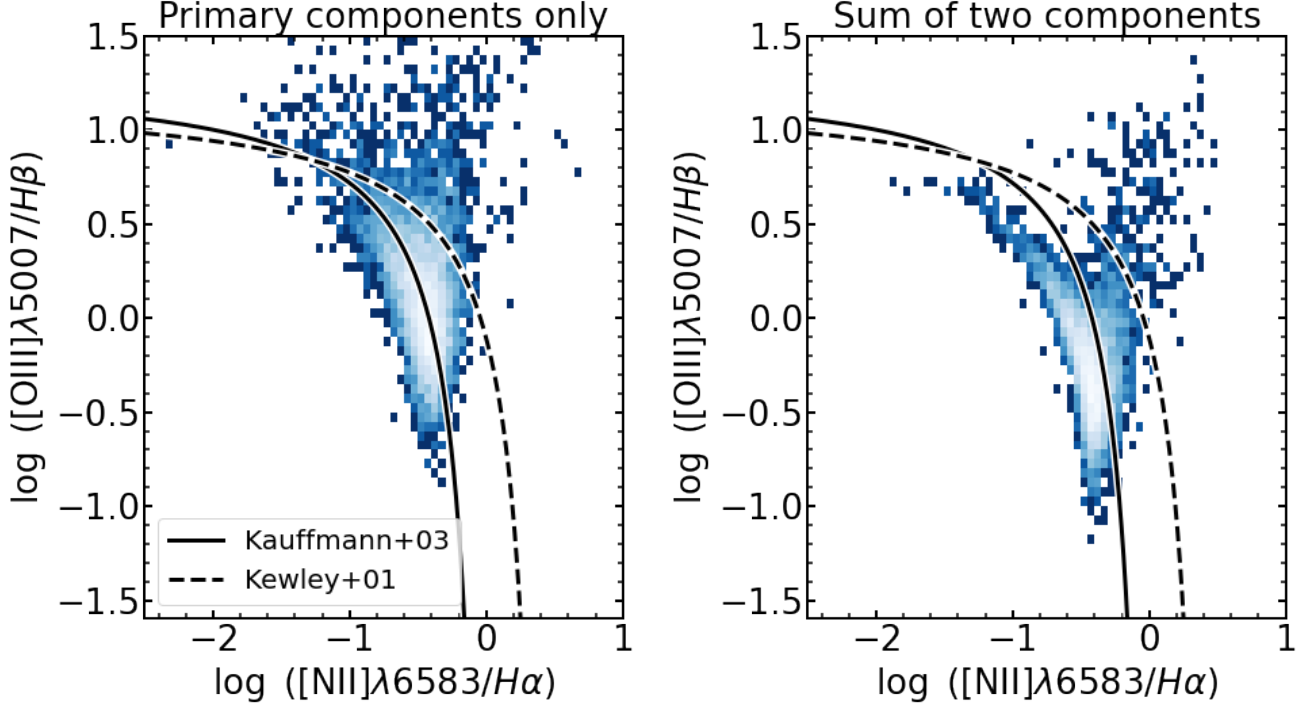


Figure 17. [NII]-BPT diagram of the 6,230 sources that have an extra component that is not an outflow component in [SII], [NII], H α , and H β , but no detected extra component in [OIII]. *Left:* The emission-line ratios are estimated with only primary components. *Right:* The emission-line ratios are estimated using the sum of the two components in the individual emission lines.

where ‘em’ denotes the different emission lines: [SII], [NII], H α , and [OIII]. The second component (em; out) is defined such that its width is always greater than the width of the primary component, leading to SR_{em} being always greater than 1.

We have 10,934 sources which show an extra component in [SII] emission line fit. Whenever an extra component is detected in [SII], we use the same profile for [NII], H α , and H β . In Figure 16, we show the distribution of these sources in the $\log(AR) - \log(SR)$ space for [SII], [NII], and H α lines. We see that there are two different distributions of sources in these three panels. The cases where the amplitude of the extra component is greater than that of the primary component ($\log(AR) > 0$) are sources without an outflow component. We visually inspect the sources where either the amplitude or σ values of the two components are nearly equal. We focus on [NII] and H α lines as they are critical for the [NII]-BPT diagnostic. Based on the visual inspection, we find the following optimum cut for separating the double-peaked emission line sources from the outflow candidates:

$$\log(AR_{[NII]}) > ((0.8 \log(SR_{[NII]})) - 0.66) \text{ OR } \log(AR_{[NII]}) > -0.2 \quad (A1)$$

OR

$$\log(AR_{H\alpha}) > ((0.8 \log(SR_{H\alpha})) - 0.66) \text{ OR } \log(AR_{H\alpha}) > -0.2 \quad (A2)$$

This criterion is shown as solid red lines in the left three panels of Figure 16. All the sources above these solid red lines (7,789/10,934) are the cases where the extra component is not considered as an outflow component.

We repeat the visual inspection for the [OIII] emission line. The right-most panel of Figure 16 shows the distribution of 18,725 sources that have an extra [OIII] component, in the $\log(AR) - \log(SR)$ space. From visual inspection, we find the following optimum cut for the [OIII] components:

$$\log(AR_{[OIII]}) > -0.09 \text{ OR } \log(SR_{[OIII]}) < 0.2 \quad (A3)$$

The solid red lines in the [OIII] panel of Figure 16 mark this criterion and the sources that are above or left of these lines (4,247/18,725) are the cases where the extra component is not considered as an outflow component.

For all the sources identified as double-peaked emission line sources, we sum the individual fluxes of the components to compute the total emission line flux. The uncertainties in these fluxes are computed by adding the uncertainties of the individual components in quadrature.

To show the importance of this, we select the 6,230 sources that satisfy the criteria mentioned in Equations A1 and A2, and do not have an extra detected component in [OIII]. We plot the [NII] BPT diagram of these sources where the emission-line ratios are computed with only the primary component (left panel of Figure 17) and with the sum of two components (right panel of Figure 17). The star-forming and AGN branches are unclear when using the primary components alone, but are visible when using the sum of the two components. The left panel of Figure 17 results in 3,255 sources ($\approx 52.2\%$) that lie on the AGN-dominated or composite region of the BPT diagram. On the other hand, the right panel results in only 1,288 sources ($\approx 20.7\%$) lying on these regions of the BPT diagram. This shows that considering the primary components alone while identifying AGN candidates leads to over-detection of candidates of interest. We therefore follow this procedure for all the emission line-related studies mentioned in this paper (Sections 3 and 4).

B. VISUAL INSPECTION OF BROAD-LINE CANDIDATES

Given that we are extending the search for broad components of $H\alpha$ to narrower widths ($\text{FWHM}(H\alpha; b) > 300 \text{ km s}^{-1}$), we want to ensure that we are including robust BL-AGN candidates in our analysis. We therefore visually inspect the spectra and fits of 556 BL sources with ($\text{FWHM}(H\alpha; b) < 1000 \text{ km s}^{-1}$) and which are BPT-AGN or BPT-composite candidates, and assign them one of the four VI Flags. These are not to be confused with the standard VI Flags used for DESI Survey Validation (Alexander et al. 2023).

- **VI Flag = 0:** This flag denotes good fits with clear broad components. We consider these as *confident* BL-AGN candidates. Of the 556 sources, we have 146 sources that satisfy this visual confidence. Figure 18 shows example cases of four such candidates.

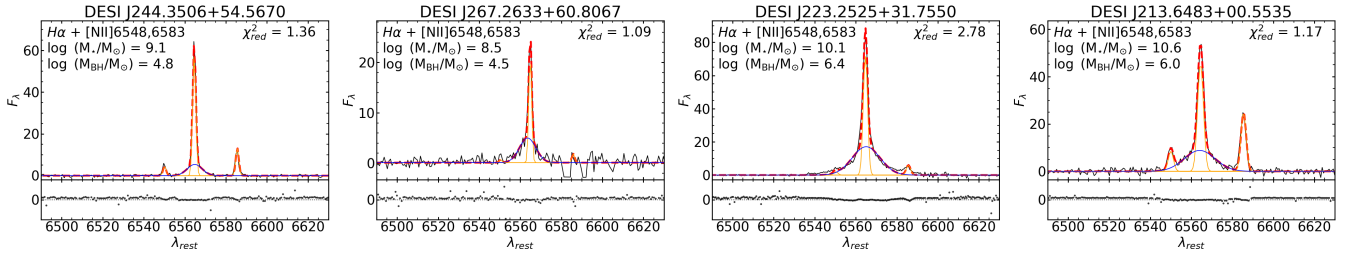


Figure 18. Example emission-line spectra and fits of the [NII] + $H\alpha$ region of four candidates with VI Flag = 0 (confident BL-AGN candidates). The spectrum is shown in black, while the best-fit model is shown in dashed red. Individual narrow and outflow components are plotted in orange, and the broad component is shown in blue. The reduced χ^2 values for these fits are shown in the upper right corner of the panels. Additionally, the stellar mass of the galaxy and the estimated BH mass derived from the broad component are noted in the top left corner of the panels.

- **VI Flag = 1:** This flag denotes cases where a broad $H\alpha$ component is detected statistically but is not obvious in visual inspection. Of the 556 sources, we have 154 such cases and we call them *tentative* BL-AGN candidates and include them in our analysis (Section 5). Figure 19 shows four example candidates with this flag.
- **VI Flag = 2:** This flag is for the candidates where the fitting code fails to identify a second or outflow component. This issue arises when the [SII] region is noisy and the fitting does not detect the second or outflow component that is visible in the [NII] $\lambda 6583$ line. Consequently, the broad $H\alpha$ component in these cases corresponds to the missed second or outflow component, rather than being attributed to the kinematics of the BLR. As a result, the estimated BH masses for these candidates are not accurate, and we exclude 252/556 sources with this VI flag. Four examples of such cases are illustrated in Figure 20.

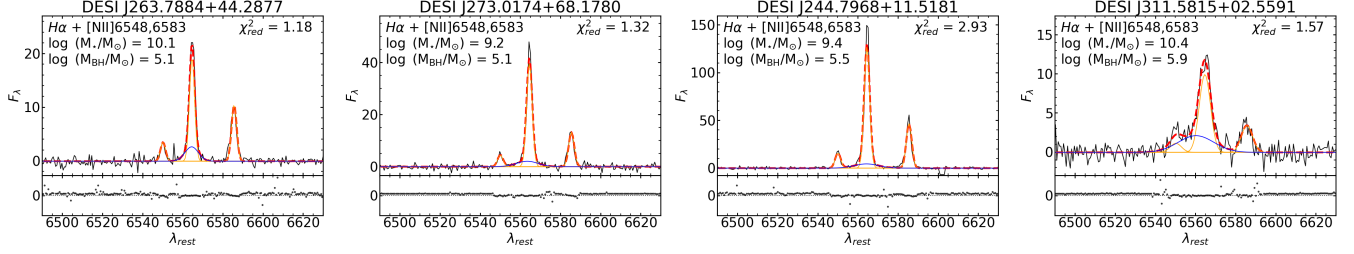


Figure 19. Example emission-line spectra and fits of the [NII] + H α region of four candidates with VI Flag = 1 (*tentative* BL-AGN candidates). The color coding of the curves and the text in the panels matches are the same as Figure 18.

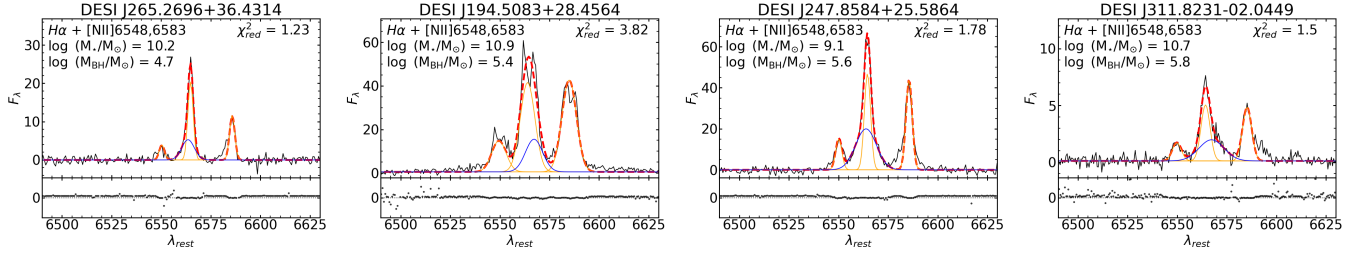


Figure 20. Example emission-line spectra and fits of the [NII] + H α region of four candidates with VI Flag = 2. The color coding of the curves and the text in the panels matches are the same as Figure 18. The indicated BH mass is estimated under the assumption that the broad component originates from the virialized gas near the BH; however, this assumption may not be valid in this case.

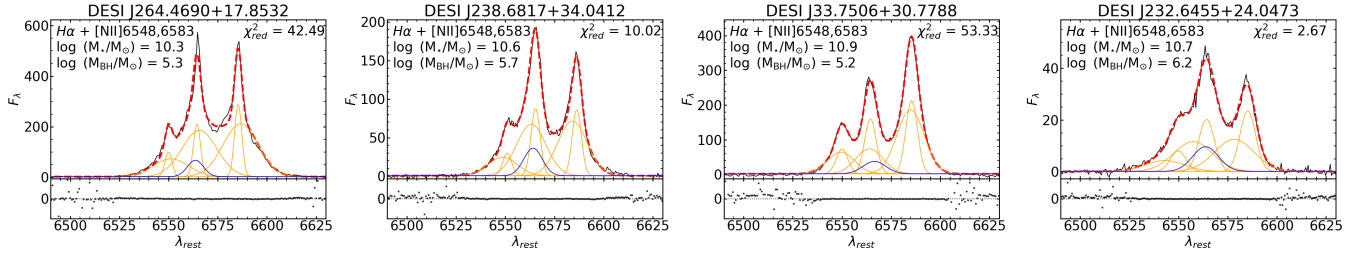


Figure 21. Example emission-line spectra and fits of the [NII] + H α region of four candidates with VI Flag = 3. The color coding of the curves and the text in the panels matches are the same as Figure 18. The indicated BH mass is estimated under the assumption that the broad component originates from the virialized gas near the BH; however, this assumption may not be valid in this case.

- **VI Flag = 3:** This flag denotes cases with uncertain fits due to complex kinematics in the H α and [NII] region, with only four candidates falling into this category (see Figure 21). All of these sources exhibit strong radio emission, as observed in VLA Sky Survey images available through the LS Sky Viewer. While this suggests the presence of an AGN, the broad H α components lead to estimates of under-massive black holes. The kinematics in these cases may be complex, making it challenging for EmFit to accurately separate the emission components. We therefore exclude these candidates from our analysis.

In Figure 22, we show the location of these visually inspected BL-AGN candidates on the $M_{\text{BH}} - M_{\star}$ space based on their VI flag. The confident (VI Flag = 0) and tentative candidates (VI Flag = 1) are shown as cyan circles and blue squares, respectively. The sources where the outflow components are possibly selected as broad components (VI Flag = 2) are shown as red crosses. Even though the assumption of BLR kinematics is not valid in such a case, we

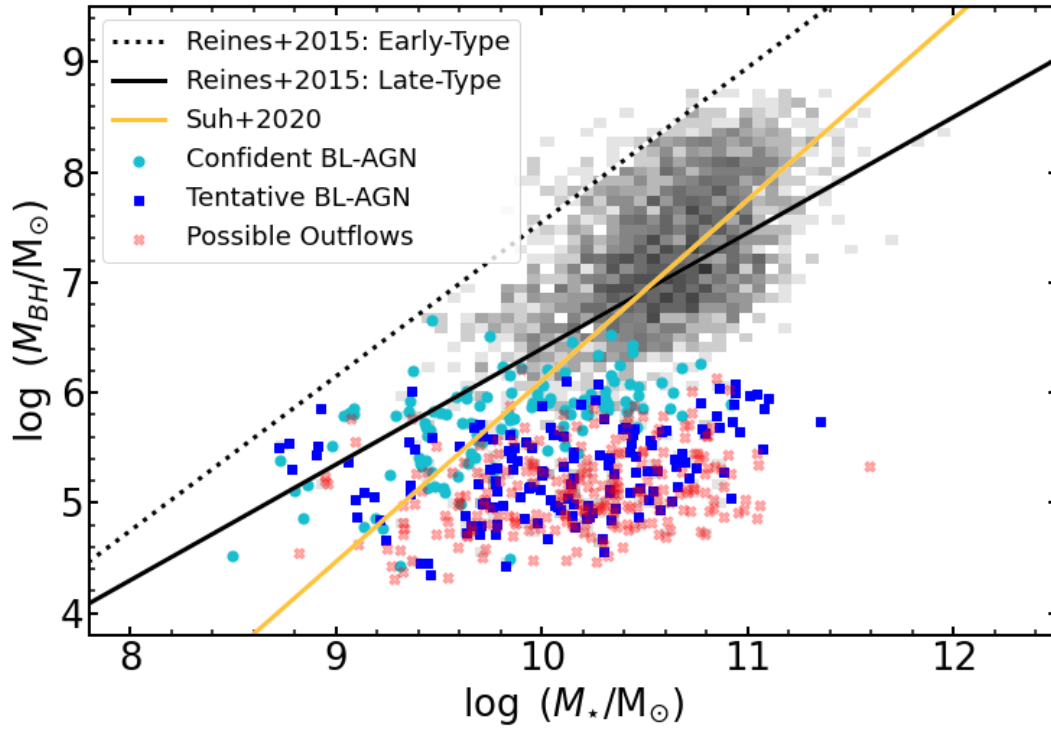


Figure 22. Position of visually inspected BL-AGN candidates on the $M_{\text{BH}} - M_*$ space. The confident (VI Flag = 0), tentative (VI Flag = 1), and outflow (VI Flag = 2) candidates are shown as cyan circles, blue squares, and red crosses, respectively.

estimate their BH masses using this extra component. The sources with possible outflows are located in the same region as tentative candidates and are removed from our bestfit estimates of the empirical relation in Section 5.3.

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